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SECONDARY EFFECTS OF PUBLIC INVESTMENTS IN HIGHWAYS AND SEWERS

ENVIRONMENTAL IMPACT CENTER, INCORPORATED

PREPARED FOR
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DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
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Statistical correlations between the amount and form of land use changes and the location of new highways and wastewater facilities were established for four major metropolitan areas individually and in combination. The statistical findings were supplemented with results from a dynamic simulation model of land use in metropolitan Washington. The analyses identified factors which seemed to explain much of the variation in location and type of development in all four regions: availability of sewer service, proximity of an area to major highways, amount of vacant land, and residential vacancy rate. However, the relative importance of each factor varied from one region to another so that although results from pooled data were acceptable in terms of their aggregate statistical significance, the set of regression equations developed from pooled data cannot be expected to produce accurate predictions in all regions.

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PREFACE

Each year, Federal, State, and local governments invest over $11.5 billion on roads and over $2.4 billion on wastewater collection and treatment facilities.[1] Typically, such infrastructure facilities accomplish their primary purposes -- speeding the flow of traffic or collecting and treating sewage -- efficiently and economically. However, there is increasing concern that these investments may have impacts extending beyond their primary accomplishments. Infrastructure facilities may affect decisions on type and location of new development since they change the relative accessibility and cost of development of land. Impacts on land use and development are termed secondary effects of the investment. Secondary effects may, in turn, be associated with a whole series of environmental, economic, and social impacts on the immediate area served by the investment and on the surrounding region.

The present study, sponsored by the Council on Environmental Quality, the Environmental Protection Agency, and the Office of Policy Development and Research, Department of Housing and Urban Development, was undertaken to investigate secondary effects of investments in:

- Highways
- Public transit facilities
- Wastewater collection and treatment facilities

The study was in two parts. The first involved an extensive review of previous research pertaining to secondary effects of infrastructure investments and of land use models which might be used to predict secondary effects. The literature review and bibliography is published in a separate volume.[2]

The second part of the study was directed at developing techniques to assist project planners and reviewers in predicting type, magnitude, and location of secondary effects associated with infrastructure investments. Case studies of recent development trends were made in four metropolitan regions -- Washington, D.C., Boston, Massachusetts, Denver, Colorado, and Minneapolis-St. Paul, Minnesota. As used in this report, the term "metropolitan region" refers to a group of urbanized and urbanizing communities with strong economic interdependence. While this corresponds roughly with the Bureau of Census' definition of a Standard

Metropolitan Statistical [illegible] (SMSA), our discussion was not strictly limited to SMSA's. Data for the four regions were analyzed using econometric techniques and simulation modeling.

The present volume documents this work. The report consists of four sections: an introduction and summary of principal findings; a technical documentation of the case studies and econometric analyses; an evaluation of the results and suggestions for further research; and an appendix summarizing the dynamic model and its application.

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I. INTRODUCTION AND SUMMARY

A. INTRODUCTION

According to the Council on Environmental Quality, "... many major federal actions, in particular those that involve ... infrastructure investments ... stimulate or induce secondary effects in the form of associated investments and changed patterns of social and economic activities. Such secondary effects, through their impact on existing community facilities and activities, may be even more substantial than the primary effects of the original action itself." [3]

The National Environmental Policy Act (NEPA) of 1969[4] and similar acts in a number of states, require government agencies to prepare, in advance, environmental impact statements for all major actions. The CEQ guidelines call for an explicit analysis of secondary effects.[3] Local governments, becoming more concerned about the implications of rapid development, have also begun to focus on impacts of infrastructure investments in stimulating or at least supporting such development.

In spite of these concerns, we lack analytical tools for predicting secondary effects or for assessing the importance of various factors which influence the magnitude, type and location of these effects. A number of studies have been directed at assessing the economic and, to a lesser extent, social impacts of highway construction; the impacts of investments in mass transit and wastewater collection and treatment have been virtually ignored.[2]

The present study was an attempt to fill this void. The focus was on effects of highways and sewers. The central purpose was to develop simple and accurate analytic techniques for forecasting secondary effects. In particular, we wished to avoid reliance on sophisticated computer models and extensive data bases. This necessarily entailed compromises. In this sense, the study was a test of the feasibility of analyzing a complex problem with a set of tools simple enough for widespread application yet accurate enough to provide useful information.

B. APPROACH

Case studies in four U.S. metropolitan regions (Washington, D.C., Boston, Denver, and Minneapolis-Saint Paul) provided an empirical base for the research. The case studies involved primarily collection of cross-sectional data pertaining to highway and sewer investments and land use changes during the period 1960 to 1970. The regions studied were selected on the basis of data availability, social and economic conditions, historical patterns of public investments, jurisdictional arrangements, and natural features. In each metropolitan region, data were collected for subregional districts ranging in size from five to fifty square miles.

The data were analyzed with standard multi-variate statistical techniques. The amount and location of (a) single-family home construction, (b) multi-family dwelling unit construction, (c) commercial land development, and (d) industrial land development were related to several factors reflecting local land market conditions, highway proximity and sewer service availability.

Multiple regression equations were estimated for each form of development in each metropolitan region. In addition, the data were pooled in order to estimate a set of equations representing average relationships across all four regions.

The statistical analyses were supplemented by a dynamic model developed to simulate land use changes as they relate to public investments. The dynamic model was applied to the Washington, D.C. region for empirical testing. The model helped to highlight factors which seemed to have an important effect on development trends.

C. SUMMARY OF FINDINGS

The analyses identified a series of factors which seemed to explain much of the variation in location and type of development in all four metropolitan regions. These factors were availability of sewer service, proximity of an area to major highways, amount of vacant land (particularly vacant land served by sewers), and residential vacancy rate. However, the relative importance of each of these factors varied substantially from one region to another, so that even though results from pooled data were acceptable in terms of their aggregate statistical significance, the set of regression equations developed from pooled data cannot be expected to produce accurate predictions in all regions.

1. Sewer Service

The influence of sewer service was expressed in terms of amount of vacant, sewered land available in each district during the 10-year forecast interval. This variable was consistently a significant factor in the regressions. Generally, the results confirm that sewer investments cause moderate to large changes in land use of all types.

The greatest influence of sewer investment seems to be on the construction of single-family housing. This was true for all metropolitan areas studied, regardless of variations in topographic and soil characteristics. In some regions municipal water supply is probably equally important, but the two services are usually provided together. Sewer service was also consistently important as a stimulus for multi-family housing construction and commercial and industrial land conversion, but the magnitude of its influence was less for each of these development types than for single-family housing construction.

These results seem to run counter to intuitive expectations. Single-family housing, the lowest density form of development, has often employed septic systems for wastewater disposal. On the other hand, high intensity development generally presupposes availability of sewer service. However, two considerations support the empirical findings. Detached, urban homes are currently constructed on small lots (usually a quarter acre or less) where septic systems are usually not satisfactory. Further, sewer facility investments during the period studied took place primarily in suburban "fringe" locations where demand for land is strongly oriented toward detached homes. Hence the statistical results accurately reflect the importance of public sewerage in the location of single-family housing.

Multi-family housing, commercial, and industrial developments are, of course, just as dependent on public wastewater facilities as new detached homes. However, demand for such intensive development is seldom high in outlying areas where new sewers are placed. Most high density development takes place in areas close to the central city where sewer service is already available and where there is relatively little vacant land. This helps to explain the lower statistical sensitivity of high density development to the amount of sewered, vacant land.

It is important to recognize that these findings do not imply that sewer investments have modest effects on intensive development in all situations. In unsewered areas where demand for multi-family housing, commercial, or industrial land is high, new sewers may stimulate major increases in construction similar to those found for single-family housing.

2. Proximity to Highways

The influence of major highway investments was measured by the proximity of a district to the nearest limited access, divided highway. Two variables were used: the base year distance and the change (1960-1970) in distance to highways.

The statistical analyses did not provide a clear picture of the impact of major highways on the location or magnitude of development. Although analyses of pooled data indicated that new highways have an impact on single-family housing construction, analyses of individual regions did not show any strong or consistent effect. In part, this was probably because most of the regions analyzed had relatively good highway accessibility even before 1960. Each new highway in a region brings a successively smaller improvement in accessibility. These diminishing marginal changes imply diminishing marginal effects on location decisions and land use. Since all the regions studied had well-developed highway networks in 1960, we may infer that the secondary effects of later highway investments were modest.

It should also be noted that the two highway measures used in these analyses tended to be collinear, and that they were not a particularly sophisticated measure of a highway's impact. Changes in relative accessibility are a more sophisticated measure, but require substantial amounts of accurate data rarely available and difficult to employ. Some earlier analyses did use changes in relative accessibility as a variable; however, the results were no better than those using the less sophisticated variables reported here.

The impact of highways on the other types of development was similarly unclear, although previous studies have shown that highway interchanges have a significant impact on particular types of development within their immediate area.[2]

3. Vacant Land

The amount of vacant land in an area generally had a positive effect on single-family housing construction and a negative influence on the more intensive forms of development. The positive relationship for single-family construction probably reflects two phenomena: (1) a diminishing, but still present possibility, of private wastewater systems in the absence of public service; and (2) a tendency of single-family housing development to focus on areas with low land prices and ease of large tract acquisition for sub-division. Intensive types of development typically do not require large tracts of land and are more strongly tied to the economic interactions and accessibility of inlying areas.

4. Residential Vacancy Rate

Not surprisingly, the amount of residential development (both single-family and multi-family) was strongly and consistently related to residential vacancy rates. Low vacancy rates indicate a strong housing market which stimulates increased residential construction.

D. CONCLUSIONS

A basic conclusion of this study, supported by both the literature review and the statistical analyses, is that public infrastructure investments can have an important impact on the location, type, and magnitude of development, particularly for single-family homes. The strong relationship with single-family homes should be interpreted as meaning that the secondary effects are particularly strong at the urban fringe since this is where most single-family home construction has taken place over the past two decades. Other types of development are also likely to be affected by infrastructure investment, although the effect was less evident in the statistical analyses than in other case studies summarized in the literature review.

A second conclusion of the study is that sewer investments seem to have stronger and more direct secondary effects than new highways. Unfortunately, there are very few case studies of sewer investments and their associated developments to supplement the general statistical analyses reported in this volume. Such studies would be valuable in providing a better understanding of the various factors which influence the generation of secondary effects by sewers. We can expect the relative importance of sewers to continue, or even become accentuated, as water pollution controls become stricter, and as new highways continue to have relatively less influence than earlier highways.

The work reported in this volume also showed that quantitative techniques can be developed, for specific regions, which will allow project planners and reviewers to estimate the magnitude and type of likely secondary effects associated with proposed infrastructure investments. Even the rather simple equations presented in this study allow these predictions to be made with reasonable confidence, although any specific projection should take careful account of the particular conditions -- topography, development pressure, land use ownership and controls -- existing in the area to be served by the investment.

The regression equations presented here are not general predictive tools that can be used with reasonable confidence in all areas. In regions not included in the case studies reported here, a useful approach would be to develop a set of new equations, similar to the ones given in this study, but reflecting the particular conditions and circumstances in the specific regions. While this requires a rather substantial data base, the alternative, application of the regression equations for the pooled sample, may be pursued only with caution. No matter what approach is taken, the application of statistically derived equations should be supplemented with a careful review of local land use plans and controls and the opinions and advice of local planners and officials.

This caution is particularly important in view of the fact that the construction industry is currently in a state of substantial flux.

Changing energy prices, demographic characteristics, personal values, construction costs, and general economic conditions may result in new developments quite different from what the United States has experienced over the past two decades. An example of these changes is the increased attention being given to mass transit investments both by localities making such investments and by families looking for new residences. Such investments, although they are too old or too new to have been included in the statistical work reported in this volume, may well provide a strong stimulus to high density residential and commercial development along their routes. Since it is not yet clear what the new trends will look like, and how much they will differ from the past, predictions of future events from statistical analyses of past trends must be viewed with great caution.

II. EMPIRICAL ESTIMATION OF SECONDARY EFFECTS

The central component of our research was a series of case studies to identify and quantify historical secondary effects in four metropolitan areas. Econometric techniques were used to relate local land use changes to land market conditions and public investments. Regression equations were developed to estimate likely secondary effects in terms of local urban development. These empirical analyses are documented in this section.

The hypotheses and specifications we formulated for testing were derived in large measure from a comprehensive review of the literature on secondary impacts. The review and annotated bibliography are presented in full in a separate volume. The following pages summarize findings of previous relevant research.

A. SUMMARY REVIEW OF PREVIOUS RELEVANT RESEARCH

1. Highways

A general conclusion of previous studies is that highways have little influence on single-family, low-density residential land use.[5-7] Retrospective case studies typically have found no significant correlations between single-family housing construction and distance to new highways or changes in accessibility, although some exceptions are evident.[8] On the other hand, studies of residential preferences (e.g., Reference 9) provide clear evidence that households are strongly influenced in their residential location decisions by accessibility, i.e., the length of the journey to work. However, such studies also show that higher-income workers -- the principal consumers of single-family housing -- are less sensitive to access. In terms of housing production, the response of professional developers to new highways cannot be gauged by the preferences of consumers, since developers need only satisfy some, but not all, consumer preferences.

Definite highway effects on multi-family residential construction have been established, but their quantitative extent is unclear. Several studies document apartment construction at urban highway interchanges,[10-12] particularly interchanges of circumferential highways.

The actual probability that any specific interchange will be so developed remains uncertain, as does the distance from the interchange to which this influence extends.

There is general agreement that new highways stimulate commercial development, particularly near interchanges.[13,14] Several studies also suggest that new urban highways have a negative impact on downtown trade[15,16] by helping to shift trade to suburban locations.

Studies of highway effects on industrial land use are internally inconsistent. Many attitude and preference surveys suggest that industries desire sites in close proximity or with good access to highways.[17-19] Statistical analyses of actual industrial location in relation to highways do not support the survey results.[20] Obviously, this preference must be counter-balanced by other factors, for example, land costs. It seems clear that a principal cause of industrial suburbanization was availability of inexpensive land (relative to the CBD) for new plants.[21] However, the shift would have been impossible without good access to suburban labor markets provided by highways.

To summarize, the available evidence suggests that households and businesses prefer good access by highway, all other factors held constant. In terms of actual location, single-family housing construction has a tenuous connection to new highways; multi-family residential and commercial development appear to be influenced by highways; and the relation of industrial development to highways is unclear.

2. Wastewater Facilities

Empirical evidence on the influence of wastewater investments on development is limited and unclear. We may note, for example, that in the various versions of EMPIRIC,[22] the influence of sewer service is inconsistent across household and employment categories. In the original Boston EMPIRIC, sewered land weighted by vacant land was positively correlated with most categories of employment change; no similar correlations were found in Washington. However, the nature of the dependent variables (i.e., district changes in shares of households by income and employment by type) and the step-wise estimation procedures used may have obscured actual correlations between sewer service and land use.

Rogers[23] found that availability of public sewer service was a significant explanatory variable for conversion of vacant and agricultural land to urban uses. It was also observed[23] that while the influence of other factors showed lags of from three to six years, sewer service availability did not. The sewer variable, however, was less influential than measures of accessibility to employment and elementary schools.

Milgram[24] found a strong correlation between (vacant) land price and public sewer service. Prices of land parcels within service areas of trunk sewers were, on average, four times higher than for parcels without sewer service. Multiple regression analyses showed that sewer service, together with allowable developmental density (defined by zoning), were the two most influential determinants of land price.

Kaiser[25] incorporated sewer service in an index of public utilities as one explanatory variable of residential subdivision development within urban areas. However, the public utilities index was much less important than a socioeconomic index reflecting various structural and demographic characteristics of neighborhoods.

The weight of evidence suggests that public sewer service is a significant factor in urban development. However, its precise importance is unclear. Part of the difficulty is caused by the fact that there is no clear cut way of defining levels of sewer service.

Most of the studies cited used a binary dummy variable for sewer service, reflecting either its presence or absence from parcels of vacant land. In evaluating the overall effects of wastewater investments rather than development of individual land parcels, it seems preferable to examine the influence of a sewer facility by the size of its service area, i.e., the amount of land in which service is available.

Few studies have attempted to ascertain the influence of sewers on different forms of land use. The EMPIRIC results for distribution of households are inconclusive; other studies[23-25] focused almost exclusively on low density single-family residential land use. Intuitively, it seems that higher density land uses should be more sensitive to the availability of public sewer service, since they require some form of group collection and disposal system.

A reasonable inference from previous work is that extensions of public sewer service stimulate residential development and that intensive multi-family and commercial uses are particularly sensitive to sewer service. A relation, if any, of industrial development to public sewers has not been established.

B. A GENERAL APPROACH TO SECONDARY EFFECTS

1. Influence of Access and Sewer Service in Urban Development

A comprehensive economic analysis of urban growth requires extensive formulation of utility functions, supply and demand curves, and market clearing processes. While significant progress has been made in specifying these relationships, the resulting mathematical models are so complex as to limit their usefulness in practical application.[26]

However, our interest is limited to the influence of public investments on urban growth. Within this relatively narrow perspective, economic analysis can be restricted to the actions of developers as producers of new structures.

Such a simplification has several appealing features. Although urban growth derives from the interdependent activities of households, businesses, and government officials, developers make the original decisions about where and what to build. A focus on their decisions reduces the necessary analysis to one group rather than several. While households and businesses may consider countless factors -- subjective as well as objective -- in making location decisions, a developer considers the few most important objective factors, since he has a limited amount of time and no motivation to evaluate individual, subjective criteria. Finally, the developer has a clearly defined motivation -- profit -- whereas households or businesses may have other immediate interests in making locational choices.

Developers are concerned with satisfying the needs and preferences of their customers while maximizing their own profits. The customers, households and businesses, desire sites that are accessible, have adequate public services, and have attractive socioeconomic features. Their preference for structural characteristics is not included in this analysis, since developers build a standardized mix rather than tailor construction to individual desires.

Because consumers have overlapping preferences, they compete for sites, driving up land prices in locations with a combination of attractive features. Developers attempt to estimate the premium households or businesses will pay for attractive sites and compare it with costs of constructing various types of structures on each site. The result of this comparison determines whether development will occur in a particular location and the form it will take.

The influence of public investments is reflected in altered attractiveness and subsequent price adjustments. Increased accessibility and higher potential density of development affect attractiveness and hence price. Since price responses are imperfect, a new highway or sewer may increase attractiveness while land costs remain unaffected for some time. In fact, anticipation of investments may allow developers to buy land at lower prices than warranted by the increased attractiveness of the location after the investment is constructed.

A single unattractive feature of a location can effectively discourage development in spite of several other attractive characteristics. Depressed residential portions of central cities, for example, often have high accessibility and relatively low land prices. Private redevelopment seldom takes place because of the unattractive socioeconomic character of such locations.

2. Factors Influencing Secondary Effects

a. Land Availability and Price -

Availability of land and raw land prices are central factors in developer decisions about where and what to build. Price and availability are usually inversely correlated. Higher prices generally require more intensive development. Hence communities with large amounts of available land at low prices are most attractive to single-family housing developers, while those with little available land, high land prices, or -- in the typical case -- both, can only be developed at higher densities.

Several combinations of conditions involving land availability and price create a strong possibility for important secondary impacts following a transportation investment. If large amounts of undeveloped land are available at a relatively low price, any increase in accessibility will have significant impacts. Modest increases in access levels may stimulate single-family development. Large increases in accessibility may encourage intensive development as well -- multi-family housing, industrial, and commercial. After a large increase in access, condominiums, two-family houses, and apartment developments are likely, with high rise apartments and business offices occurring in "pockets" of high accessibility such as highway interchanges or near transit stations. If, on the other hand, only small amounts of land are available and existing prices are high, modest accessibility increases will have no major impacts, while large increases may stimulate high density construction.

Land availability and price play a similar role in determining the impact of sewer investments. Here the important factor is how much undeveloped land is in the service area of the new sewer, and the related range of prices. Large amounts of vacant land at low prices signify a potential for single-family housing construction. Higher prices and/or lesser amounts of undeveloped land make multi-family residential, industrial, and commercial development more likely.

Because highways traverse and serve many communities with different combinations of land availability and price, they may cause a full range of secondary impacts. Radial highways in metropolitan areas, for example, may stimulate single-family housing construction in outlying areas with low land prices and extensive undeveloped land, mixed single-family and higher density construction in partially developed suburban communities, and high-intensity commercial, industrial and residential construction in the fully-developed inlying suburbs. The last impact, however, is atypical; central areas are much more likely to lose population and business activities after highways because of migration to the suburbs.

b. Land Use Controls -

Zoning and other forms of local land use control are intended to protect existing residents from discordant forms of development. They limit the use and intensity to which individual parcels of land may be put. In theory, therefore, they influence the amount of development of each kind that can occur in a community and potentially limit secondary effects.

The simple fact is that local land use plans are seldom effective unless they are made in conjunction with a long range master plan and are rigorously enforced. This combination is the exception rather than the rule. In most communities or counties, variances are so easy to obtain that zoning provides almost no control of land use. Thus, even where comprehensive land use plans exist, pressures to rezone counter to planned uses often render them ineffectual.

In evaluating the likelihood of secondary impacts in a community, the most significant features of its land use controls are the existing amounts of undeveloped land zoned for each category of use and the historical record of how thoroughly zoning has been enforced. If variances have been difficult to obtain, then developmental impacts probably will be restricted to levels near the amount of properly zoned vacant land for each category of use. The most common implication of this situation is a limitation on the amounts of industrial, commercial, and multi-family residential development that can occur, with little or no limitation on single-family housing construction. However, if variances are easy to gain, then zoning will have no moderating or controlling influence on impacts; land availability and price, access, and sewer service will determine the form and amount of development that occurs.

c. Income Level of Existing Residents -

There is some evidence that, with all other factors held constant, developers prefer to build single-family housing in areas where the existing population have higher than average income levels. This influence is caused by the preferences of families who desire detached single-family homes for attractive socioeconomic features. They desire the "right" kind of neighbors, as well as attractive structural characteristics implied by upper income levels. This influence is not a dominant one, but it suggests that where a new highway or sewer line serves communities similar in most respects but varying in income levels, the upper income communities will receive more single-family construction than low or middle income areas. The relationship does not hold for other forms of development.

Communities with very high average income, on the other hand, are likely to be exclusive with regard to multi-family housing, or large commercial and industrial development. The exclusion may also extend to relatively dense single-family housing -- two or more units per acre. Such exclusive practices, usually reflected in land use controls or policies, serves to constrain new development and, therefore, secondary effects. Very high income ranges, therefore, can signify that important secondary effects are unlikely in spite of land availability, substantial increases in accessibility, or new sewer investments.

d. Existing Levels of Access and Sewer Service -

The availability of transportation and public sewer facilities and existing levels of service in a community or area strongly affect the probability for major secondary impacts following a new investment. Increases in accessibility beyond a certain point, or extension of sewer service in locations where substantial amounts of sewered land are already available, have only a marginal effect on the attractiveness of the area for development. It is large and dramatic shifts in accessibility or sewered vacant land that create the potential for significant secondary effects. In metropolitan areas with an existing and extensive network of highways, further investments will, on the whole, have a modest influence on development. However, this does not imply that no important secondary effects will occur; almost always, a few portions of the region will experience major increases in access. But the extent of significant impacts will be highly localized, rather than widespread.

The importance of existing accessibility levels is more complex than that of sewered available land. Since access changes are ultimately reflected in land prices, developers of low density structures, e.g., single-family housing, must build where accessibility is relatively low, while the higher intensity developers can afford locations with high access. Therefore, in some intermediate range, higher accessibility causes an area to become decreasingly attractive to low density developers and, at the same time, increasingly attractive to higher intensity developers. If a predominantly single-family community with moderate accessibility experiences a large increase in access, the ultimate effect, as land prices adjust, will be to discourage single-family housing construction. Such an impact, of course, would depend on the other conditions in the community -- land availability and existing price, zoning, etc. On the other hand, extensions of sewer service area or increased sewer or treatment plant capacities do not discourage any form of development; their positive influence is, however, smaller where already existing levels of service are adequate.

e. Vacancy Rates -

Residential, commercial, and industrial vacancy rates are indices of local market conditions to developers. High vacancy rates serve as indications of lack of demand for existing structures at current price levels. At any particular time, of course, some structures will be vacant as transactions take place. This "frictional" vacancy rate can range as high as several percent. Rates above this level imply slack markets, while lower rates suggest market tightness.

Highways and accessibility changes alter demand levels and may thus tighten the market and reduce vacancy rates. We would expect, however, that new construction would occur only after existing stocks of structures had proved insufficient to meet demand, unless the structures themselves were outdated. Therefore, short term secondary effects of highways should be less substantial when vacancy rates are high.

Wastewater investments are somewhat different in that they affect the production side rather than the demand side of urban development. Therefore, in spite of reduced costs, developers may have little incentives to build in areas with high vacancy rates because of the absence of demand. New sewer facilities in such instances should have minimal secondary effects.

The combination of vacancy rates and land availability provides perhaps the best simple measure of developmental potential in an area. Vacancy rates are indicative of development pressure. Land availability indicates what kind of development is likely: large amounts of vacant land imply a potential for low intensity (e.g., detached homes) construction, while small amounts suggest that dense development will occur. It is possible, of course, to identify some situations where these general rules do not hold, for example, overcrowded areas in central cities. These two indicators are, however, adequate for most areas outside the urban core.

3. Interactions Among Factors

We have discussed above some factors which determine the likelihood for secondary effects in an area. Although we have treated these separately, it is the combination of such factors in a community that determines whether new investments will significantly affect development there. In many areas, these factors are related to each other in such a fashion that certain combinations of conditions are much more likely than others. For example, high levels of accessibility usually reflect concentrations of activities and, therefore, small amounts of vacant land, as well as high land costs. Conversely, low accessibility generally indicates dispersed activities, substantial amounts of undeveloped land, and low prices. There is an implicit progression in these relationships, from large tracts of undeveloped unsewered land, low prices, and low access to fully developed and sewered, high priced, very accessible areas. The former are characteristic of the urban-rural fringe and the latter of mature urban communities. Transportation and wastewater investments cause secondary impacts by creating combinations of conditions that hasten this progression.

Individual communities and towns are interdependent within any given metropolitan area in the sense that households, businesses, and developers evaluate the characteristics of each town relative to other communities in the region. Conditions in a single community, therefore, have no absolute importance alone, but rather are important relative to conditions in other parts of the area. Each community is an element of the larger system. This relativistic character makes it difficult to associate amounts of development with specific values for land price, accessibility, land availability, and other characteristics.

Interactions have been ignored in the quantitative analysis that follows. Clearly, the quantitative results are only approximations justified by their relative simplicity as against a dynamic model which would capture interactions between variables and changes with time. Simplicity was necessary since local officials generally do not have adequate resources for an extensive analysis of potential secondary impacts.

C. DEVELOPMENT OF QUANTITATIVE RELATIONS

1. Specification

In order to place the above hypotheses in the context of local markets for land and structures, a simple system of simultaneous equations was specified.

The underlying model is one in which households and businesses have demands for particular kinds of structures in particular geographic zones. These demands are matched with existing supplies of structures through a market mechanism in which prices adjust so as to ration supply and allocate it to the highest bidder. As demands increase, prices are bid up and these in turn provide signals to developers to increase the supply of particular kinds of structures in particular zones. Given the expected prices at which different kinds of structures will be sold, the developer makes decisions on the basis of expected profitability. Expected prices generate the revenue side of the profit equation, while costs of alternative kinds of development are determined by land costs, planning costs, and construction costs.

While it would be desirable to model this mechanism explicitly, the crucial variable, price of each type of structure in each zone, is not available from published data sources. Therefore, a reduced-form version excluding price variables was specified:

$$\Delta P = f(\Delta H, H, Z_c, R, V, W, \Delta W, t) \qquad (1)$$

$$\Delta C = g(\Delta P, K, L, Z_n, X, W) \tag{2}$$

$$K = h(r, X, W, S_1) \tag{3}$$

$$L = k(H, W, X, t) \tag{4}$$

where for each structure type in each local market area:

ΔP = change in expected selling price
H = highway service measure
ΔH = change in highway service
Z_c = socioeconomic characteristics
R = regional growth rates
V = vacancy rate
W = wastewater service
ΔW = change in wastewater service
ΔC = construction (number of units)
K = costs of construction per unit structure
L = land costs
X = number of acres of undeveloped land
Z_n = zoning index
S_1 = soil characteristics
t = local tax rate
r = interest rate (cost of capital)

Each variable carries implicit time and location subscripts. The change variables, indicated by Δ's, occur over some pre-specified time interval; all other variables represent conditions in the base year of that interval.

Equations 1, 3, and 4 can be substituted into 2 leaving a single vector equation (reduced form) to be estimated:

$$\Delta C = f(\Delta H, H, Z_c, R, V, W, \Delta W, t, r, X, S_1, Z_n) \tag{5}$$

Several important simplifications have been made to derive this structure and reduced form. The most drastic is for equation (1). Rather than modeling proper demand and supply functions for the entire stock of structures and positing particular mechanisms for market clearing and price adjustment, it is assumed that changes in variables that increase demand have an upward pressure on prices. Developers take cognizance of changes and projections of factors affecting demand and form expectations of price movements in the absence of substantial change in the stock of structures. Highway service, neighborhood (zone) characteristics, wastewater service, and tax rates are all assumed to affect the price that users would pay for structures of certain sorts in particular zones. Regional growth rates of particular user classes (population and business) are assumed to affect the expected increase in demand pressures, while vacancy rates suggest how much additional demand can be accommodated without eliciting price increases. Highway service and changes in highway service are reflections of actual transport systems, actual and expected congestion on various segments, and expected additions to the system.

The only other equation in which highway service enters, (4), indicates that improved accessibility will increase land prices, and this in turn, through (2) will affect the rate of construction adversely. In fact, the role of land prices and demand factors in (2) is purposefully ambiguous. If markets for land were perfectly competitive and all actors had equal access to information, the price of land should capture all excess profits that would be associated with developing it for its most profitable use. That is, if developers were to acquire land at competitively determined prices, the profitability of developing any parcel of land in the metropolitan area would be equal, reflecting the cost of capital, for the most profitable use of the land. In such a world, equation (4) would be redundant. In fact, we know that the world does not provide equal information to all parties. The possibilities of "sharp" developers being spurred to develop properties that they are able to buy cheaply from naive owners are real. If firms are not perfect profit maximizers, high land prices will force them to consider high density developments that they might otherwise not consider.

The actual quantities of construction that take place are determined by equation (2). The assumption is that construction levels will vary directly with levels of profitability. Expected price increases will stimulate construction, while high construction and land costs will dampen the supply response to increased demand. Zoning and wastewater services can facilitate or retard implementation of otherwise profitable development. While there is room to argue that zoning and sewerage decisions are accommodative to developmental pressures, we consider them to be exogenously-determined variables that impinge on the developer's decision. Finally, availability of large tracts of undeveloped land makes the problem of land assembly simpler and should be an important variable explaining the quantity of development that takes place.

Equation (3) merely states that construction costs are affected by interest rates, soil conditions, availability of large tracts of land, and presence or absence of wastewater facilities.

Land prices as determined by equation (4) are assumed to be affected by highway service, wastewater facilities, tax rates, and the quantity of undeveloped land in the zone.

When the substitutions are made into (5), it is obvious that the coefficients of each of the independent variables in (1)-(4) are not recoverable. Rather, the coefficients estimated for (5) will be combinations of the various coefficients from the basic equations. For instance, the coefficient associated with highway service will embody both the demand factors of (1), the land-price effects from (4), and indirectly, the effect of land price on construction from (2). However, as argued earlier, the principal effects of transportation investments on development come through the highway access-induced premium that will be paid by demanders of structures.

In contrast, the wastewater service variable enters each of the equations. It is to be anticipated, however, that the effect on demand will be minimal, while the influence of sewer service on construction costs will be significant.

The reduced form (equation 5) served as the basic model in subsequent statistical analyses. Further simplifications were made because of problems with lack of data on tax rates, soil conditions, zoning, and regional growth vectors. Interest rates were omitted since they are generally uniform within a metropolitan area. In later stages of the research, additional variables were introduced to try and represent explicitly competition for land among consuming groups. These changes are documented in subsequent portions of this section.

Because of the simplified nature of the regression specifications and the combination of several parameters from the structural system of equations into single coefficients for estimation, it was difficult to make inferences from statistical results concerning the adequacy or validity of the original equations. Since we were interested in single-equation models rather than a recursive simultaneous equation system, no attempt at such inferences was made. The structural form was used principally as a guide for early specifications.

2. Definition of Variables

Multiple regression analyses were used to estimate versions of the above reduced form. Data were acquired for four U.S. metropolitan areas: Boston, Massachusetts; Denver, Colorado; Minneapolis-St. Paul, Minnesota; and Washington, D.C. For each of the regions, EMPIRIC model data sets[27] constituted the principal source of information on land use. Supplemental data on housing and vacancy rates were acquired from the U.S. Census of Housing. Precise definitions of variables and related data sources are provided later in this section.

All of the data were cross-sectional. Regions are subdivided into districts numbering from 85 in Minneapolis-St. Paul to 182 in Denver. Each district represents a unit of observation for our variables; cross-sectional data from 1960 represent the base-year in each case, while the dependent and investment (policy) variables reflect 1960-1970 changes.

Four dependent variables were used in most regressions: single-family and multi-family housing construction, and commercial and industrial land conversion. The basic set of explanatory variables included five measures of public investments and two measures of local market conditions. Two forms of highway service variable were used: accessibility and proximity to highways. The full set of variables is defined in detail below.

a. Dependent Variables -

1. Number of single-family dwelling units in the district - The definition of a housing unit is that of the 1970 Housing Census, User's Guide, Part I, p. 113, U.S. Department of Commerce, October 1970. Data were obtained from Table H-1, "Occupancy and Structural Characteristics of Housing Units." Single-family homes comprise structures with one unit.

2. Number of multi-family dwelling units in the district - The same Census tables were used and all structures with more than one housing unit were included.

3. Number of acres of commercial land in the district - Primary data (EMPIRIC) came from aerial photographs in each city, with the following kinds of land use classified as commercial:

- Hotels, motels, tourist homes or tourist camps
- Retail establishments, including: food, supermarket, drug store, hardware
- Mixed retail, services, and residential (either 1-story mixed retail and services, or 2-story building with 2nd floor residential)
- Eating and drinking places
- General retail and dry goods (clothing, apparel, accessories, department store, furniture, appliances)
- Lumber, building materials, feed (retail)
- Gasoline service stations
- Automotive dealer, farm and heavy equipment, marine equipment, trailer sales (retail)
- Personal services: barber-beauty shops, cleaning and dyeing, collection, shoe-shine
- Office buildings -- business services, dental services, electronics (research and development), legal and professional services, medical services, offices and office buildings not classified elsewhere (does not include transportation, communication, and utilities), repair services (except automotive repair), wholesale services (without stocks)
- Finance, insurance, real estate services -- banking services, savings and loan offices, finance and insurance corporation services, insurance and real estate brokers services
- Vacant office buildings

- Hospital -- including clinic, institutional home, nursing home, old people's home, rest home, orphanage
- Indoor recreation, entertainment -- including athletic club, gymnasium, bowling alley, clubs, lodges, fraternities, sororities, indoor swimming pool, skating rink, indoor theater, movie house, night club, YMCA, YWCA
- Cultural, religious -- including art gallery, museum, assembly hall

4. Number of acres of industrial land in the district - The following categories of land were included in the industrial category:

Durable Manufacturing:

- Furniture, lumber, other durable goods -- manufacturing
- Metals and allied fabricating -- manufacturing
- Machinery, transportation equipment -- manufacturing (except electrical machinery)
- Scientific and professional instruments, electrical machinery -- manufacturing

Non-Durable Manufacturing:

- Food, allied products -- manufacturing
- Textiles, apparel, allied products -- manufacturing
- Chemicals, petroleum, plastics, rubber, allied products -- manufacturing
- Paper, allied products -- manufacturing
- Printing, allied industries
- Leather, leather products -- manufacturing
- Vacant manufacturing building -- all types of manufacturing

Non-Manufacturing:

- Bus, taxi -- motor passengers terminal, depot, garage
- Truck transportation
- Dock, port facilities
- Vacant transportation, communications, public utility building
- Intensive wholesale, storage (enclosed) -- allied products, appliance, automotive, dry goods, electrical, food, hardware
- Extensive wholesale, storage (open yards) -- auto salvage, building materials, chemicals, lumber, petroleum (gas-oil), wrecking yard
- Vacant wholesale, warehouse, storage building

Extensive Industrial:

- Railroad facilities -- depot, repair shop, yards
- Airport facilities (non-military)

- Mine, quarry, sand and gravel pit
- Utilities, communications -- electric, gas, sanitary services, plant sub-station, valve station, power line, gas line, row, radio, tv antenna, telegraph-telephone facilities

b. Explanatory Variables -

1. Base year distance (in miles) to the nearest major highway - Measurements were made on maps of each region. All limited access, divided highways were included. Some ambiguities were encountered where highways changed from limited to free access or from divided to undivided within the region. In such cases we did not include stretches that were undivided or free access. For definition of highway types, see: Highway Research Board, "Highway Capacity Manual," Special Report 87, Division of Engineering and Industrial Research, Washington, National Academy of Sciences-National Research Council, 1965.

2. Change in distance (1960-1970) (in miles) to the nearest major highway - The same definitions and procedures were used.

3. Base year highway accessibility - Accessibility is defined as follows:

$$Ac_{ip} = \frac{\beta^{\alpha}}{\Gamma(\alpha)} \sum_{j=1}^{N} A_{jp} (t_{ij})^{\alpha-1} \exp(-\beta t_{ij})$$

where: Ac_{ip} = accessibility of district i to activity p
A_{jp} = activity value for district j and activity p
N = number of districts
t_{ij} = travel time for district i to district j
α = shape parameter of the gamma distribution
β = scale parameter of the gamma distribution
$\Gamma(\alpha)$ = the Gamma function

The variables defining accessibility are travel times between zones and amount of activities (in this case, employment and households). The other parameters, α and β, are functions of observed trip distributions in each region.

4. Change in highway accessibility (1960-1970), defined as above - To avoid simultaneity of forecast quantities, 1960 activity distributions are used with projected 1970 travel times to compute 1970 accessibilities. Use of 1970 activity distributions would, of course, require as an input the quantities to be forecast.

5. Sewered vacant land - Public sewer service was measured by vacant, sewered land (in acres) in each district. Vacant land is defined in

(6) below. Originally, base year sewered vacant land and change (1960-1970) in sewered vacant land were included as separate variables. There was, however, a high degree of correlation between the two; accordingly, they were combined into a single sewer service variable.

6. Vacant, developable land (in acres) in the district - Privately owned agricultural land, vacant lots, forest land and woodlands are considered vacant developable land. Undevelopable land is land that is swamp or has excessive slope (greater than 15%) or has some other clear impediment to development.

7. The total residential vacancy rate in the district - The vacancy rate was defined as the ratio of total housing units less total households divided by total housing units.

3. Problems with Estimation of Variables

a. Dependent Variables -

The definition of commercial land given above was not consistently applied in EMPIRIC data for different regions. A major discrepancy apparently arose from the inclusion of additional categories -- principally government and institutional -- in commercial land for Boston and Washington. Access to the original raw data proved impossible; accordingly, such inconsistencies could not be corrected. However, in view of the highly aggregate nature of the commercial (and industrial) variables, resulting errors in the regressions affect primarily values of the constant. Errors in the estimated coefficients of the independent variables arising from this inconsistency in the data are probably small.

b. Explanatory Variables -

Sewered vacant land - Definitions of base year, sewered vacant land and of change (1960-1970) in sewered vacant land in a district are easy to formulate but difficult to apply with data usually available. For each district, the definitions are:

(base year sewered vacant land)

= (vacant land in sewer service area)
= (total land in sewer service area) - (developed land in sewer service area)

(change in sewered vacant land)

= (1970 sewered vacant land) - (base year sewered vacant land)

The first difficulty in using these definitions is the precise delineation of sewer service area. Usually "legal" service areas are proscribed for sewers within which new hookups may be authorized. Unfortunately, these boundaries tend to expand as developmental pressure increases. An alternative measure of the service area of interceptor sewers is the area physically bounded by drainage patterns and topography. An interceptor sewer typically serves a definite catchment area. However, this measure tends to overstate effective service area, since portions of the drainage basin are usually too distant to allow hookups without substantial further investments in collector sewers. Furthermore, the drainage-defined sewer area may be expanded at any time by construction of pumping stations and force mains to transport wastewater between watersheds.

The service area used in the regressions was the legal service area, wherever possible. Where legal service areas were not available, we assumed that service areas extended one mile on both sides of interceptor and trunk sewers. This is admittedly a crude measure, but is more likely to reflect effective service areas than topographically defined boundaries.

With service area thus defined, the total land in the service area of a sewer within a given district is easily obtained. However, developed land within the service area is not known. What is available for each district is total developed land. The assumption was made that all developed land in the base year was within the service areas of existing sewers. With this assumption, base year sewered vacant land is given by total land in sewer service area less total developed land in the district. This procedure doubtless introduced some error, since some fraction of developed land within a district was probably unsewered. However, as we point out below, this error is counterbalanced to some extent by the approximations made in estimating changes in sewered, vacant land.

Change in sewered, vacant land is estimated by calculating newly sewered land using, as above, the legal service area for the new sewers (or a one-mile band on both sewer sides) and subtracting base year, sewered vacant land. Since in the final specification, a variable consisting of base year plus change in sewered, vacant land was used, this combined variable can be obtained by calculating total land in the service area for all sewers in the district and subtracting total developed land within the district. An appropriate correction is made for land that is not developable (parks, other public lands, and land that is swamp or has a slope greater than 15%).

In applying the regression expressions to a proposed new sewer, the simplest way of calculating the sewer related variable is to obtain total, developable land within the legal service area of sewers in the district, including the proposed sewer, and subtract total developed land within the district.

D. STUDY REGIONS AND SAMPLE CHARACTERISTICS

The four metropolitan areas used in the case studies were selected according to several criteria. Of overriding concern was the availability of a unified, comprehensive data base for each region to minimize field data collection. Beyond this requirement, however, our principal objectives were to select regions representative of U.S. metropolitan areas in general, and to obtain a mix of regional conditions that might influence the extent or magnitude of secondary effects. Areas studied were Boston, Massachusetts; Denver, Colorado; Minneapolis-St. Paul, Minnesota; and Washington, D.C.

These regions meet the stated criteria. Two Eastern Seaboard cities represent the dense population centers of the country. Boston, of course, is characteristic of the old, traditional urban center, with a slow rate of growth and somewhat stagnant economy. Washington, on the other hand, is of the new order, growing explosively with no sign of a slowdown. Minneapolis-St. Paul and Denver are typical of Midwestern and Western cities, with moderate to strong growth around established urban core areas. Economically, the regions range from service-oriented (Boston) and manufacturing (Twin Cities) to government-oriented (Washington, D.C.) and an even mix of businesses (Denver). Jurisdictionally, the Boston region is based on municipalities, the Washington region on counties, while Denver and Minneapolis-St. Paul reflect a blend of authority among these two levels of government. The regions also vary broadly in physical characteristics such as size, climate, topography, and soils. Hence the influence of these factors on secondary effects are represented at least roughly in the case studies.

For statistical work, each metropolitan area (the Census SMSA with minor changes) was subdivided into a number of districts, ranging from 85 for Minneapolis-St. Paul to 182 for Denver. Metropolitan population and land use characteristics and district averages are given in Tables 1 through 6.

The characteristics summarized in Table 2 are generally relevant to the topics considered in this study and help define the metropolitan areas selected for study. In terms of 1970 population, these SMSA's ranked 7th (Washington), 8th (Boston), 15th (Minneapolis-St. Paul) and 27th (Denver) among the approximately 250 SMSA's in the country. In terms of population growth rates, Boston was among the slowest growing regions; Denver and Washington among the fastest; and Minneapolis-St. Paul near the average value of 17.0% for the 150 SMSA's with population over 200,000 in 1970.

Tables 7 through 11 present simple correlation coefficients for the principal variables in each region and in the pooled sample for all regions.

Table 1. CHARACTERISTICS OF METROPOLITAN AREAS IN 1960[a,b]

	Boston	Denver	Minneapolis-St. Paul	Washington
Total Land				
(thousands acres)	1,021	643.1	1,045	718.1
Population				
(thousands)	3,108	915.8	1,483	2,077
Change	8.6%	31.1%	22.4%	34.0%
Single-Family Housing				
(thousands units)	449.2	221.9	318.2	350.0
Change	4.1%	24.3%	15.9%	26.1%
Multi-Family Housing				
(thousands units)	446.0	77.7	146.0	251.0
Change	16.4%	60.7%	43.4%	55.1%
Commercial Land				
(thousands acres)	29.0	3.09	7.56	16.20
Change	69.4%	76.5%	53.4%	65.7%
Industrial Land				
(thousands acres)	38.2	20.2	27.3	7.49
Change	8.0%	37.0%	23.4%	66.2%

[a] Study area in each metropolitan region was slightly different from SMSA.

[b] Changes are for 1960-1970, except for Washington commercial and industrial land use data which are for 1960-1968.

Table 2. CHARACTERISTICS OF 1970 SMSA'S[a]

	Boston	Denver	Minneapolis-St. Paul	Washington
Population Distribution				
Central Cities	23.3%	41.9%	41.0%	26.4%
Percent Change	-8.1	4.2	-6.1	-1.0
Outside Central Cities	76.7%	58.1%	59.0%	73.6%
Percent Change	11.3	63.7	55.9	61.9
Employment Distribution				
Manufacturing	21.5%	17.8%	26.4%	3.8%
Wholesale & Retail Trade	22.7	24.6	24.1	19.6
Services[b]	32.2	24.5	24.0	27.6
Government	13.7	18.6	13.6	37.7
Unemployment	4.3	3.3	3.4	2.6
Single-Family Housing Distribution				
Percent of Total Units in SMSA	43.7%	68.0%	63.3%	54.0%
Percent of Units in Central Cities	15.0	58.0	48.7	36.9
Percent of Units Outside Central Cities	53.9	76.7	76.6	61.3
Automobile Ownership & Use				
Percent Households with:				
No Automobile	24.8%	12.0%	14.7%	20.1%
One Automobile	49.5	41.1	47.1	45.5
Two or More Automobiles	25.6	46.9	38.2	34.3
Percent Making Work Trip by Automobile	67.4	86.4	81.9	73.2

[a] Data are for 1970; changes for 1960-1970.

[b] Includes F.I.R.E. (Finance, Insurance, and Real Estate).

Table 3. REGIONAL CHARACTERISTICS - BOSTON
(Number of Districts (N) = 125; Mean District Size = 8,200 acres)

	Development per District			
	Mean 1960	Mean 1970	Mean Change	% Change
Single-Family Dwelling Units	3600	3740	140	3.9
Multi-Family Dwelling Units	3570	4155	585	16.4
Commercial Land (acres)	230	390	160	69.6
Industrial Land (acres)	125	160	35	28.0

	Local Conditions (per District)	
	Mean per District	Standard Deviation
Base Year Distance to Highway (miles)	3.0	3.07
Change in Distance to Highway (miles)	1.1	2.63
Sewered Vacant Land (Base + Change)(acres)	650.	1266.
Base Year Total Vacant Land (acres)	4500.	4017.
Base Year Residential Vacancy Rate[a] (%)	8.4	10.

[a] This value is the mean of vacancy rates for each district. Average values for the area as a whole were 6.0% in 1960 and 3.9% in 1970.

Table 4. REGIONAL CHARACTERISTICS - DENVER
(Number of Districts (N) = 182; Mean District Size = 3,530 acres)

	Development per District			
	Mean 1960	Mean 1970	Mean Change	% Change
Single-Family Dwelling Units	1220	1515	295	24.2
Multi-Family Dwelling Units	430	685	255	59.3
Commercial Land (acres)	17	30	13	76.5
Industrial Land (acres)	100	133	33	33.0

	Local Conditions (per District)	
	Mean per District	Standard Deviation
Base Year Distance to Highway (miles)	2.7	2.3
Change in Distance to Highway (miles)	1.2	1.8
Sewered Vacant Land (Base + Change)(acres)	794.	1110.
Base Year Total Vacant Land (acres)	2151.	4169.
Base Year Residential Vacancy Rate[a] (%)	6.7	3.6

[a] This value is the mean of vacancy rates for each district. Average values for the area as a whole were 5.8% in 1960 and 4.2% in 1970.

Table 5. REGIONAL CHARACTERISTICS - MINNEAPOLIS-ST. PAUL
(Number of Districts (N) = 85; Mean District Size = 12,200 acres)

	Development per District			
	Mean 1960	Mean 1970	Mean Change	% Change
Single-Family Dwelling Units	3740	4340	600	16.0
Multi-Family Dwelling Units	1720	2460	740	43.0
Commercial Land (acres)	58	89	31	53.4
Industrial Land (acres)	297	369	72	24.2

	Local Conditions (per District)	
	Mean per District	Standard Deviation
Base Year Distance to Highway (miles)	2.5	2.5
Change in Distance to Highway (miles)	.99	1.8
Sewered Vacant Land (Base + Change)(acres)	1984.	2364.
Base Year Total Vacant Land (acres)	9016.	10843.
Base Year Residential Vacancy Rate[a] (%)	7.7	9.0

[a] This value is the mean of vacancy rates for each district. Average values for the area as a whole were 5.4% in 1960 and 3.5% in 1970.

Table 6. REGIONAL CHARACTERISTICS - WASHINGTON, D.C.
(Number of Districts (N) = 103; Mean District Size = 6,970 acres)

	Development per District			
	Mean 1960	Mean 1970	Mean Change	% Change
Single-Family Dwelling Units	3400	4290	890	26.2
Multi-Family Dwelling Units	2440	3785	1345	55.1
Commercial Land (acres)	99	164	65	65.7
Industrial Land (acres)	73	121	48	65.8

	Local Conditions (per District)	
	Mean per District	Standard Deviation
Base Year Distance to Highway (miles)	2.8	2.3
Change in Distance to Highway (miles)	1.3	1.9
Sewered Vacant Land (Base + Change)(acres)	2950.	4682.
Base Year Total Vacant Land (acres)	4665.	7357.
Base Year Residential Vacancy Rate[a] (%)	7.7	8.5

[a] This value is the mean of vacancy rates for each district. Average values for the area as a whole were 5.5% in 1960 and 4.2% in 1970.

Notes for Tables 7 - 11

VARIABLE NAMES FOR SIMPLE CORRELATIONS

SFUNIT = 1960 single-family housing (dwelling units)
SFUNIT70 = 1970 single-family housing (dwelling units)
SFCON = 1960-70 single-family housing construction (dwelling units)
MFUNIT = 1960 multi-family housing (dwelling units)
MFUNIT70 = 1970 multi-family housing (dwelling units)
MFCON = 1960-70 multi-family housing construction (dwelling units)
CLU = 1960 commercial land use (acres)
CLU70 = 1970 commercial land use (acres)
COMCON = 1960-70 increase in commercial land (acres)
ILU = 1960 industrial land use (acres)
ILU70 = 1970 industrial land use (acres)
INDCON = 1960-70 increase in industrial land (acres)
D60 = 1960 distance to highway (miles)
DELTAD = 1960-70 change in distance to highway (miles)
VLU = 1960 vacant land (acres)
SSERVICE = 1960 + 1960-70 change in sewered vacant land (acres)
TVACRATE = total residential vacancy rate (percent)
TOTLU = total land (acres)

Table 7. SIMPLE CORRELATION COEFFICIENTS - BOSTON

SECTION 1

	SFUNIT	SFUNIT8	SFCON	MFUNIT	MFUNIT8
SFUNIT	1.0000				
SFUNIT8	0.9516	1.0000			
SFCON	-0.2801	0.0286	1.0000		
MFUNIT	0.2426	0.0785	-0.5439	1.0000	
MFUNIT8	0.3389	0.1762	-0.5517	0.9822	1.0000
MFCON	0.4805	0.5034	0.0094	-0.1856	0.0026
CLU	0.2530	0.2405	-0.0719	0.2247	0.2531
CLU8	0.2288	0.2518	0.0422	0.0970	0.1162
COMCON	0.1340	0.2043	0.2022	-0.1191	-0.1186
ILU	0.3967	0.3538	-0.1852	0.4441	0.4869
ILU70	0.2034	0.2191	0.0230	0.1048	0.1296
D60	-0.3035	-0.2866	0.0920	-0.2512	-0.2690
DELTAD	-0.2042	-0.1824	0.0944	-0.0955	-0.1029
VLU	-0.3058	-0.1571	0.5038	-0.4467	-0.4705
SSERVICE	0.5126	0.5941	0.1883	-0.0677	0.0068
TVACRATE	-0.2134	-0.2596	-0.1165	-0.1634	-0.2082
TOTLU	-0.0208	0.1216	0.4472	-0.4026	-0.3995

Table 7 (continued). SIMPLE CORRELATION COEFFICIENTS - BOSTON

SECTION 2

	MFCON	CLU	CLU8	COMCON	ILU
MFCON	1.0000				
CLU	0.1277	1.0000			
CLU8	0.0913	0.9335	1.0000		
COMCON	0.0135	0.5949	0.8436	1.0000	
ILU	0.1823	0.2480	0.2261	0.1354	1.0000
ILU70	0.1200	0.1171	0.1552	0.1726	0.6273
D60	-0.0700	-0.0891	-0.0886	-0.0651	-0.1482
DELTAD	-0.0298	-0.0968	-0.0892	-0.0549	0.0098
VLU	-0.0829	-0.0141	0.0795	0.1992	-0.1528
SSERVICE	0.3957	0.3337	0.3220	0.2220	0.2278
TVACRATE	-0.2189	-0.0509	-0.0734	-0.0883	-0.1955
TOTLU	0.0538	0.2149	0.3038	0.3592	-0.0122

SECTION 3

	ILU70	D60	DELTAD	VLU	SSERVICE
ILU70	1.0000				
D60	-0.0124	1.0000			
DELTAD	0.0607	0.8370	1.0000		
VLU	0.1142	0.4037	0.4042	1.0000	
SSERVICE	0.1136	-0.1666	-0.0953	-0.0225	1.0000
TVACRATE	-0.1040	0.3075	0.1524	0.3339	-0.1827
TOTLU	0.1797	0.2884	0.2808	0.9172	0.1311

SECTION 4

	TVACRATE	TOTLU
TVACRATE	1.0000	
TOTLU	0.3047	1.0000

Table 8. SIMPLE CORRELATION COEFFICIENTS - DENVER

SECTION 1

	SFUNIT	SFUNIT70	SFCON	MFUNIT70	MFCON
SFUNIT	1.0000				
SFUNIT70	0.7809	1.0000			
SFCON	-0.2843	0.3725	1.0000		
MFUNIT70	0.2469	0.0484	-0.2932	1.0000	
MFCON	0.2911	0.2307	-0.0791	0.5999	1.0000
CLU	0.4682	0.2953	-0.2547	0.2805	0.1858
CLU70	0.3117	0.3464	0.0655	0.1437	0.1517
COMCON	0.0328	0.2384	0.3237	-0.0428	0.0538
ILU	-0.0597	-0.1088	-0.0819	-0.0702	-0.0609
ILU70	-0.0721	-0.1019	-0.0525	-0.0954	-0.0623
INDCON	-0.0817	-0.0118	0.1037	-0.1457	-0.0310
D60	-0.2340	-0.1437	0.1097	-0.1448	-0.0351
DELTAD	-0.1057	-0.0462	0.0632	-0.1606	-0.0489
VLU	-0.3414	-0.2310	0.1371	-0.2221	-0.1450
SSERVICE	-0.2791	0.0279	0.4534	-0.2287	-0.0767
TVACRATE	-0.4791	-0.2918	0.2638	-0.0579	-0.2430
TOTLU	-0.2987	-0.1989	0.1245	-0.2198	-0.1362

Table 8 (continued). SIMPLE CORRELATION COEFFICIENTS - DENVER

SECTION 2

	CLU	CLU70	COMCON	ILU	ILU70
CLU	1.0000				
CLU70	0.7350	1.0000			
COMCON	0.1709	0.7937	1.0000		
ILU	0.0710	0.0089	-0.0508	1.0000	
ILU70	0.0711	0.0208	-0.0335	0.9788	1.0000
INDCON	0.0288	0.0592	0.0602	0.3034	0.4923
D60	-0.1422	-0.1909	-0.1498	0.2815	0.2793
DELTAD	-0.0592	-0.1390	-0.1489	0.0658	0.0783
VLU	-0.1601	-0.1424	-0.0633	0.0813	0.1421
SSERVICE	-0.0824	0.0373	0.1281	0.1098	0.1843
TVACRATE	-0.0624	0.0338	0.1052	-0.0511	-0.0124
TOTLU	-0.1297	-0.1230	-0.0623	0.1994	0.2552

SECTION 3

	INDCON	D60	DELTAD	VLU	SSERVICE
INDCON	1.0000				
D60	0.1029	1.0000			
DELTAD	0.0849	0.8002	1.0000		
VLU	0.3152	0.3757	0.1740	1.0000	
SSERVICE	0.3905	0.2003	0.0792	0.5357	1.0000
TVACRATE	0.1594	0.1554	0.0667	0.3552	0.3510
TOTLU	0.3393	0.3954	0.1517	0.9639	0.5399

SECTION 4

	TVACRATE	TOTLU
TVACRATE	1.0000	
TOTLU	0.3160	1.0000

Table 9. SIMPLE CORRELATION COEFFICIENTS - MINNEAPOLIS-ST. PAUL

SECTION 1

	SFUNIT60	SFUNIT70	SFCON	MFUNIT60	MFUNIT70
SFUNIT60	1.0000				
SFUNIT70	0.9308	1.0000			
SFCON	-0.2205	0.1512	1.0000		
MFUNIT60	0.3235	0.1691	-0.4237	1.0000	
MFUNIT70	0.4599	0.3339	-0.3529	0.9562	1.0000
MFCON	0.3922	0.5094	0.2987	-0.3033	-0.0111
CLU	0.5899	0.5341	-0.1700	0.6270	0.7204
CLU7	0.4542	0.5700	0.2928	0.2916	0.3460
COMCON	0.2268	0.4437	0.5708	-0.1749	-0.0503
ILU	0.1315	0.1591	0.0691	0.0881	0.0867
INDLU7	0.2074	0.3026	0.2467	0.0120	0.0352
INDCON	0.1632	0.3167	0.4037	-0.0437	0.0458
D60	-0.2722	-0.2697	0.0165	-0.1657	-0.2249
DELTAD	-0.1014	-0.0739	0.0771	-0.0449	-0.0902
VLU	-0.5279	-0.4287	0.2838	-0.3233	-0.4087
SSERVICE	0.0209	0.2652	0.6512	-0.2735	-0.1761
TVACRATE	-0.3547	-0.4037	-0.1180	-0.0788	-0.1634
TOTLU	-0.4565	-0.3514	0.2969	-0.3147	-0.3884

Table 9 (continued). SIMPLE CORRELATION COEFFICIENTS - MINNEAPOLIS-ST. PAUL

SECTION 2

	MFCON	CLU	CLU7	COMCON	ILU
MFCON	1.0000				
CLU	0.2034	1.0000			
CLU7	0.1303	0.6262	1.0000		
COMCON	0.4339	0.2556	0.5475	1.0000	
ILU	-0.0187	0.2369	0.1166	0.0358	1.0000
INDLU7	0.0735	0.1965	0.2800	0.1267	0.8115
INDCON	0.2985	0.2131	0.3329	0.3675	0.2575
D60	-0.1663	-0.2635	-0.3069	-0.0998	-0.1243
DELTAD	-0.1403	-0.1238	-0.1048	0.0122	-0.0828
VLU	-0.2261	-0.4306	-0.2798	-0.0162	0.0254
SSERVICE	0.3610	0.0438	0.3656	0.6565	0.0461
TVACRATE	-0.2627	-0.2071	-0.2230	-0.1801	0.0329
TOTLU	-0.1893	-0.3660	-0.2227	0.0262	0.0684

SECTION 3

	INDLU7	INDCON	D60	DELTAD	VLU
INDLU7	1.0000				
INDCON	0.6254	1.0000			
D60	-0.1888	-0.2112	1.0000		
DELTAD	-0.0754	-0.0423	0.7200	1.0000	
VLU	-0.0754	-0.2116	0.6377	0.2140	1.0000
SSERVICE	0.1378	0.3070	-0.0845	-0.0312	0.0647
TVACRATE	-0.1489	-0.3587	0.4144	0.1180	0.4922
TOTLU	-0.0332	-0.1849	0.6302	0.2009	0.9910

SECTION 4

	SSERVICE	TVACRATE	TOTLU
SSERVICE	1.0000		
TVACRATE	-0.1239	1.0000	
TOTLU	0.1097	0.4942	1.0000

Table 10. SIMPLE CORRELATION COEFFICIENTS - WASHINGTON, D.C.

SECTION 1

	SFDU	SFDU70	SFCON	MFDU	MFDU70
SFDU	1.0000				
SFDU70	0.9078	1.0000			
SFCON	0.0293	0.4458	1.0000		
MFDU	0.3467	0.1791	-0.3131	1.0000	
MFDU70	0.4724	0.3668	-0.1339	0.8296	1.0000
MFCON	0.3225	0.3865	0.2328	-0.0238	0.5385
CLU60	0.1932	0.2134	0.0961	0.0221	0.0929
CLU70	0.2508	0.3090	0.2011	-0.0892	0.0138
COMCON	0.2625	0.3499	0.2737	-0.1908	-0.0739
ILU60	0.0995	0.1489	0.1425	-0.0366	0.0200
ILU70	0.1388	0.2118	0.2087	-0.1157	-0.0095
INDCON	0.1534	0.2883	0.2406	-0.1923	-0.0478
D60	-0.0784	-0.0093	0.1452	-0.1454	-0.1554
DELTAD	-0.0870	-0.0818	-0.0093	-0.1308	-0.1278
VLU	-0.2086	-0.0052	0.4328	-0.3589	-0.3014
SSERVICE	0.0062	0.1973	0.4570	-0.3065	-0.1583
TVACRATE	-0.0475	-0.0643	-0.0519	-0.0106	-0.1301
TOTLU	-0.0971	0.1113	0.4727	-0.3322	-0.2315

Table 10 (continued). SIMPLE CORRELATION COEFFICIENTS - WASHINGTON, D.C.

SECTION 2

	MFCON	CLU60	CLU70	COMCON	ILU60
MFCON	1.0000				
CLU60	0.1331	1.0000			
CLU70	0.1593	0.9105	1.0000		
COMCON	0.1555	0.6323	0.8961	1.0000	
ILU60	0.0911	0.5702	0.4879	0.3021	1.0000
ILU70	0.1575	0.5647	0.5951	0.5087	0.9158
INDCON	0.2045	0.3950	0.5730	0.6495	0.5359
D60	-0.0588	-0.0047	-0.0119	-0.0172	0.0849
DELTAD	-0.0315	-0.1438	-0.1585	-0.1426	-0.2079
VLU	0.0020	0.2229	0.3201	0.3604	0.3931
SSERVICE	0.1791	0.3380	0.4104	0.4059	0.4449
TVACRATE	-0.2169	-0.0138	0.0294	0.0698	0.0177
TOTLU	0.0868	0.2943	0.3903	0.4152	0.4518

SECTION 3

	ILU70	INDCON	D60	DELTAD	VLU
ILU70	1.0000				
INDCON	0.8299	1.0000			
D60	0.0712	0.0318	1.0000		
DELTAD	-0.1748	-0.0786	0.7918	1.0000	
VLU	0.4708	0.4435	0.2837	-0.1000	1.0000
SSERVICE	0.4976	0.4280	0.2340	-0.0857	0.6992
TVACRATE	0.0579	0.0972	0.0215	0.0680	0.0697
TOTLU	0.5347	0.4963	0.3120	-0.0926	0.9808

SECTION 4

	SSERVICE	TVACRATE	TOTLU
SSERVICE	1.0000		
TVACRATE	-0.0223	1.0000	
TOTLU	0.7377	0.0300	1.0000

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Table 11. SIMPLE CORRELATION COEFFICIENTS - POOLED SAMPLE

SECTION 1

	SFUNIT	SFUNIT70	SFCON	MFUNIT	MFUNIT70
SFUNIT	1.0000				
SFUNIT70	0.9270	1.0000			
SFCON	-0.0731	0.3064	1.0000		
MFUNIT	0.3273	0.1879	-0.3311	1.0000	
MFUNIT70	0.4434	0.3265	-0.2573	0.9506	1.0000
MFCON	0.4026	0.4624	0.2077	-0.0694	0.2436
CLU60	0.3189	0.2837	-0.0552	0.3027	0.3324
CLU70	0.3211	0.3190	0.0331	0.1972	0.2314
COMCON	0.2618	0.3061	0.1493	0.0123	0.0461
ILU60	0.1476	0.1372	-0.0098	0.1138	0.1181
ILU70	0.1366	0.1624	0.0849	0.0210	0.0403
INDCON	0.0598	0.1328	0.2013	-0.1347	-0.0954
D60	-0.1873	-0.1493	0.0783	-0.1673	-0.1822
DELTAD	-0.1300	-0.1063	0.0473	-0.0922	-0.1025
VLU	-0.1748	-0.0370	0.3453	-0.2175	-0.2202
SSERVICE	0.1217	0.3163	0.5321	-0.1298	-0.0390
TVACRATE	-0.1440	-0.1389	-0.0038	-0.0764	-0.1300
TOTLU	-0.0350	0.0953	0.3421	-0.1743	-0.1574

Table 11 (continued). SIMPLE CORRELATION COEFFICIENTS - POOLED SAMPLE

SECTION 2

	MFCON	CLU60	CLU70	COMCON	ILU60
MFCON	1.0000				
CLU60	0.1227	1.0000			
CLU70	0.1277	0.9424	1.0000		
COMCON	0.1098	0.6793	0.8855	1.0000	
ILU60	0.0237	0.1126	0.0915	0.0443	1.0000
ILU70	0.0641	0.1032	0.1188	0.1173	0.8977
INDCON	0.1142	0.0461	0.1182	0.1955	0.1892
D60	-0.0628	-0.0364	-0.0322	-0.0202	0.0631
DELTAD	-0.0412	-0.0883	-0.0876	-0.0697	-0.0208
VLU	-0.0281	0.0310	0.0836	0.1405	0.1600
SSERVICE	0.2802	0.1315	0.1720	0.1947	0.1441
TVACRATE	-0.1791	-0.0013	0.0136	0.0316	-0.0426
TOTLU	0.0389	0.1524	0.2056	0.2393	0.2339

SECTION 3

	ILU70	INDCON	D60	DELTAD	VLU
ILU70	1.0000				
INDCON	0.5737	1.0000			
D60	0.0815	0.0230	1.0000		
DELTAD	0.0059	0.0325	0.7976	1.0000	
VLU	0.2276	0.1054	0.3645	0.1279	1.0000
SSERVICE	0.2211	0.2031	0.0607	-0.0322	0.3898
TVACRATE	-0.0321	-0.0473	0.2356	0.0949	0.2926
TOTLU	0.2955	0.1345	0.3511	0.0968	0.9713

SECTION 4

	SSERVICE	TVACRATE	TOTLU
SSERVICE	1.0000		
TVACRATE	-0.0192	1.0000	
TOTLU	0.4268	0.2767	1.0000

E. REGRESSION ANALYSES

A series of multiple regression analyses was performed for each dependent variable. Several issues that could not be resolved a priori were addressed empirically. Most important were normalization of the equations to account for variations in district size, selection of highway service variables, and changes in the specification to reflect competition for land among alternative user groups. These issues, of course, have a major bearing on whether a simple reduced expression can adequately model secondary impacts.

The issue of normalization presents both theoretical and practical problems. Theoretically, there is a choice between extensive specifications involving absolute amounts or levels of stocks and activities in each district and intensive specifications involving proportions or rates. The first specification implies that amounts of construction (e.g., number of units) are related to amounts of characteristics in a district (e.g., number of acres vacant). The second implies that rates or proportions of construction (e.g., units/acre) are related to proportions of district characteristics (e.g., percent vacant). The practical issue is whether variation in district size leads to statistical bias because of lumpy data. The statistical problem that results is heteroscedasticity -- residual errors with changing variance correlated with the size of the districts.

As a preliminary resolution of this issue, we chose a normalized specification in which land-related variables (e.g., construction, total vacant and sewered vacant land) were divided by total acres in each district. This specification was used to establish whether amounts of construction are partially determined by district size and to correct for the possibility that larger districts have larger random variations in construction than smaller districts. This preliminary specification was subsequently modified.

Selection of highway service variables -- accessibility levels or proximity to highways -- was principally a matter of testing alternative combinations for statistical significance and explanatory power. Accessibility seems preferable because it measures highway influence in a more detailed way. However, calculations of accessibilities require substantial amounts of data and thus would be difficult to use in practice. Distance to highway, a gross measure of highway influence, has the advantage of being easy to determine.

The lack of representation of competing or interacting land uses is perhaps the greatest weakness of the specification. We hoped to alleviate this problem in the course of the statistical analyses by including new explanatory variables as simple indicators of competition and its effects. However, competition proved far too complex to be addressed by the simple structural forms adopted here.

A series of regressions with each dependent variable was carried out in order to resolve these issues. In some cases, several iterations were made using data for alternative groups of regions. The general procedure followed is illustrated by the analyses for single-family housing given below. It is interesting to note that the simpler specifications and variables were generally more successful than more complex variables or expressions.

1. Single-Family Housing Construction

a. Initial Normalized Equation -

The initial specification for single-family housing construction (units/acre) included base year and change in access to employment, percent sewered vacant land, and percent total vacant land as explanatory variables. Separate regressions were run on data for Boston, Denver, and Washington.

Results for these tests are shown in Table 12. Surprisingly, base year accessibility had negative and significant coefficients in two of the three regions. These negative coefficients, which occurred rather consistently for single-family construction, seem counter-intuitive since access is a desirable characteristic of locations. However, a reasonable interpretation is that high levels of base year accessibility imply land prices too high to permit low density housing construction.

Change in access to employment had the theoretically expected positive effect for Denver and Washington. Low levels of significance, indicated by the t statistics, may have been caused by collinearity between the two access variables (r = .94). Since no data were available on change in accessibility for Boston, a change in distance to highway variable was used.

Sewered vacant land and total vacant land had positive effects on single-family housing construction. The fact that parameters for sewered vacant land are larger than those for vacant land in two of the three regions provided the first indication that public sewer service is an important determinant of single-family housing construction. In spite of multi-collinearity, most of the t statistics are significant at the 10% or 5% level.

b. Normalized with Vacancy Rate and Competing Land Uses -

A second specification was made to test change in distance to a major highway as an indicator of highway construction in all regions, while retaining base year access to employment. In addition, three new independent variables were included to represent factors influencing the construction of single-family units. The first variable was total residential vacancy rate, a measure of housing market tightness within each district. To take into account competition for land with other

Table 12. SINGLE-FAMILY HOUSING CONSTRUCTION NORMALIZED BY DISTRICT SIZE[a]

Specification: $\left(\frac{\text{Single-Family Housing Construction}}{\text{Total Land}}\right) = b_1(\text{Base Year Access to Employment})$

$+ b_2(\text{Change in Access to Employment}) + b_3\left(\frac{\text{Sewered Vacant Land}}{\text{Total Land}}\right) + b_4\left(\frac{\text{Vacant Land}}{\text{Total Land}}\right)$

$+$ Constant

Explanatory Variable:		Denver	Washington	Boston
Base Year Access to Employment:	$b_1 =$	-13.2	-2.12	.076
	$t_1 =$	(-1.930)	(-1.201)	(.399)
Change in Access to Employment:	$b_2 =$	.58	1.899	-
	$t_2 =$	(.950)	(.654)	-
Change in Distance to Highway:		-	-	.143
		-	-	(1.542)
$\left(\frac{\text{Sewered Vacant Land}}{\text{Total Land}}\right)$:	$b_3 =$	.715	.286	.207
	$t_3 =$	(5.741)	(1.290)	(1.430)
$\left(\frac{\text{Vacant Land}}{\text{Total Land}}\right)$:	$b_4 =$	.417	.036	.546
	$t_4 =$	(3.172)	(.137)	(5.159)
Constant:	$a_1 =$	-.32	.053	-.34
Coefficient of Determination (R^2):		0.39	0.11	0.25
F-value:		28.0	2.10	10.0

[a] Approximate values for $t_{.05}$ and $F_{.01}$ are 1.66 and 3.17.

types of development, both the observed multi-family units constructed and industrial land conversion over the 1960-1970 interval were included in the single-family equation. It was expected that large amounts of competing land uses would reduce single-family construction.

Regression results for this single-family formulation are shown in Table 13. For Denver and Washington, the sewer service, vacant land and access variables show relative stability compared to the previous results. Vacancy rates and the competing land use variables perform as expected for Denver, in which all the independent variables except industrial construction are significant at the .025 level. In Washington, however, the vacancy and competing land variables show positive but generally insignificant relationships. Further examination of the calculated vacancy rates for Washington revealed that the inclusion of military housing in the total stock coupled with demolition of housing for highway construction created errors in the variable subsequently corrected.

The inclusion of the new variables in the Boston equation caused a reversal in signs of the highway variables, suggesting multi-collinearity. While the vacancy rate parameter was negative and significant as hypothesized, competing land use variables were positive and insignificant. The fact that all of the land in Massachusetts is incorporated at the municipal level rather than the county level may explain in part apparent co-location of single-family, multi-family, and industrial development, since our districts conform to municipal boundaries.

While the competing land variables seem appropriate for Denver, their unexpected parameters in Washington and Boston suggest that small analysis districts are necessary to model competition effects. In addition, questions of land assembly, demolition of existing stock or conversion from one type of use to another are problems which should be addressed in modeling interactions between intensive development types as they bid for land resources. These questions are essentially dynamic in character, while our approach is a static representation. Therefore, competing land use variables were omitted from subsequent regressions.

c. Normalized with Proximity to Highways -

A third specification with distance to highway replacing access measures was estimated for Minneapolis, Washington, and Boston. In this case, base year distance and forecast year distance to highway were included, with negative parameters expected for both. Competing land use variables were excluded, while residential vacancy rate was retained. Results are shown in Table 14.

Parameters for the highway variables remained inconsistent. Coefficients for sewer service, vacant land, and vacancy rates are relatively stable. For Boston, a dummy variable was added to reflect the orienta-

Table 13. SINGLE-FAMILY HOUSING CONSTRUCTION, SECOND FORMULATION[a]

Specification:

$$\left(\frac{\text{Single-Family Housing Construction}}{\text{Total Land}}\right) = b_1(\text{Base Year Access to Employment}) + b_2(\text{Change in Distance to Highway}) + b_3\left(\frac{\text{Sewered Vacant Land}}{\text{Total Land}}\right) + b_4\left(\frac{\text{Vacant Land}}{\text{Total Land}}\right) + b_5(\text{Residential Vacancy Rate}) + b_6\left(\frac{\text{Multi-Family Housing Construction}}{\text{Total Land}}\right) + b_7\left(\frac{\text{Industrial Land Conversion}}{\text{Total Land}}\right) + \text{Constant}$$

Explanatory Variable		Denver	Washington	Boston
Base Year Access to Employment:	b_1 =	-6.38	-1.04	-.057
	t_1 =	(-2.305)	(-1.198)	(-.326)
Change in Distance to Highway:	b_2 =	.163	.075	-.089
	t_2 =	(2.070)	(.435)	(-1.402)
(Sewered Vacant Land/Total Land:	b_3 =	.755	.293	.181
	t_3 =	(6.829)	(1.365)	(1.171)
(Vacant Land/Total Land):	b_4 =	.490	.002	.496
	t_4 =	(3.909)	(.009)	(6.516)
Residential Vacancy Rate:	b_5 =	-.539	.048	-.471
	t_5 =	(-3.475)	(.172)	(-2.436)
(Multi-Family Construction/ Total Land):	b_6 =	-.047	.051	.078
	t_6 =	(-2.076)	(1.418)	(.366)
(Industrial Land Conversion/ Total Land):	b_7 =	-1.333	3.53	.445
	t_7 =	(-1.372)	(.902)	(.577)
Constant	a_1 =	-.338	.065	-.22
Coefficient of Determination (R^2):		.46	.12	.43
F-value:		21.1	1.87	12.4

[a] Approximate values for $t_{.05}$ and $F_{.01}$ are 1.66 and 3.17.

Table 14. SINGLE-FAMILY HOUSING CONSTRUCTION, THIRD FORMULATION[a]

Specification:

$$\left(\frac{\text{Single-Family Housing Construction}}{\text{Total Land}}\right) = b_1(\text{Base Year Distance to Highway}) + b_2(\text{Forecast Year Distance to Highway}) + b_3\left(\frac{\text{Sewered Vacant Land}}{\text{Total Land}}\right) + b_4\left(\frac{\text{Vacant Land}}{\text{Total Land}}\right) + b_5(\text{Residential Vacancy Rate}) + \text{Constant}$$

Explanatory Variable:		Minneapolis	Washington	Boston
Base Year Distance to Highway:	$b_1 =$	-.012	+.012	-.006
	$t_1 =$	(-1.007)	(+.418)	(-.730)
Forecast Year Distance to Highway:	$b_2 =$	-.011	-.042	.004
	$t_2 =$	(-.638)	(-.884)	(.295)
(Sewered Vacant Land/Total Land):	$b_3 =$	.106	.304	.299
	$t_3 =$	(2.100)	(1.290)	(1.826)
(Vacant Land/Total Land):	$b_4 =$	.481	.175	.545
	$t_4 =$	(5.868)	(.736)	(6.884)
Residential Vacancy Rate:	$b_5 =$	-.430	.031	-.710
	$t_5 =$	(-1.503)	(.089)	(-2.855)
Dummy Variable for Second Homes: (Boston only)				.104 (1.274)
Constant:	$a_1 =$	-.173	-.05	-.25
Coefficient of Determination (R^2):		.31	.07	.31
F-value:		7.15	1.42	8.97

[a] Approximate values for $t_{.05}$ and $F_{.01}$ are 1.6- and 3.17.

tion in a few coastal towns toward second homes and seasonal rental of dwelling units, causing very high vacancy rates. The coefficient is positive as expected, and borders on significance.

The performance of these three specifications across metropolitan area was quite varied. R^2's ranged from .07 to .46, while the F statistics were significant at the 5% level or better with a single exception. Among individual variables, sewer service was consistent in terms of sign and significance, although changes in magnitude of the coefficients from region to region are apparent. Vacant land and vacancy rates were also generally significant. Results for the highway variables were disappointing in the sense that no consistent relationships were established. In view of the multi-collinearity problems in the data, it was not possible to conclude with confidence that no such relationships existed.

Examination of residuals for this series of regressions revealed strong correlations between error terms and district size. However, this correlation was in the opposite direction than anticipated, i.e., decreasing district size increased variance in errors. Since virtually all the small districts were in central cities, this finding may reflect different conditions in or near the urban core, as well as urban renewal activities unrelated to the private market factors considered here.

As a statistical heteroscedasticity test, absolute values of error terms were regressed with total land in each district. The sample was selected from the specification which showed the least heteroscedasticity. Results showed district size to be significant at the one percent level in explaining residual values.

d. Unnormalized and Pooled -

Normalization by district size clearly increased the heteroscedasticity of the residuals since, in effect, it weighted the small districts more heavily than the large districts. Therefore, a second series of regressions was run using unweighted linear specifications. These tests were run on all four regions and with a pooled sample from all regions. Explanatory variables included base year and change in distance to highway, sewer service, vacant land, and residential vacancy rate. For the pooled sample, dummy variables were added to distinguish between regions.

Results are shown in Table 15. Sewer service is the only completely stable explanatory variable in terms of sign and significance. Vacant land and vacancy rate fulfill a priori expectations with single exceptions. Only the two highway variables are inconclusive in their results for individual cities, although the pooled result seems correct. It should be noted, however, that the base year distance to highway and change in distance were strongly collinear in all of the samples, which may explain the instability.

Table 15. SINGLE-FAMILY HOUSING CONSTRUCTION, UNNORMALIZED[a]

Specification: Single-Family Housing Construction = b_1(Base Year Distance to Highway) + b_2(Change in Distance to Highway) + b_3(Sewered Vacant Land) + b_4(Vacant Land) + b_5(Residential Vacancy Rate) + Constant)

Explanatory Variable:		Minneapolis	Denver	Washington	Boston	Pooled
Base Year Distance to Highway:	b_1 =	-195.2	21.0	-65.3	36.9	-52.3
	t_1 =	(-2.726)	(.576)	(-.564)	(.948)	(-1.775)
Change in Distance to Highway:	b_2 =	189.9	-1.92	99.0	-70.0	65.8
	t_2 =	(2.532)	(-.045)	(.736)	(-1.577)	(1.975)
Sewered Vacant Land:	b_3 =	.270	.310	.092	.099	.165
	t_3 =	(7.361)	(6.289)	(2.422)	(1.984)	(9.683)
Vacant Land:	b_4 =	.056	-.035	.052	.136	.036
	t_4 =	(4.718)	(-2.462)	(1.954)	(7.776)	(4.762)
Residential Vacancy Rate:	b_5 =	-2128	2944	-659	-2654	-584
	t_5 =	(-1.926)	(2.134)	(-.784)	(-3.850)	(-1.072)
Constant:	a_1 =	21.1	-126	473	-340	188
Dummy Variables: Minneapolis						-134 (-1.082)
Boston						200 (1.787)
Washington						-172 (-1.688)
Coefficient of Determination (R^2):		.56	.24	.24	.38	.33
F-value:		20.2	11.4	6.2	14.7	29.8

[a] Approximate values for $t_{.05}$ and $F_{.01}$ are 1.66 and 3.17.

In every region except Boston, the coefficient of the sewer service variable is substantially larger than that of the vacant land variable. This suggests that unsewered vacant land is less influential in a single-family residential development than sewered vacant land under ordinary circumstances. In the Boston region, however, a significant portion of single-family housing construction in the 1960's was suburban large-lot homes, for which septic tanks could be used. In Boston, unsewered vacant land had a larger influence than sewered vacant land.

The dummy variables reflect differences between regions as a whole and variations in district sizes between regions. However, there is no clear correspondence between either aggregate growth rates or district growth rates and the values of the dummy variables. Hence unincluded exogenous factors are being represented.

F. REGRESSION RESULTS

The most promising form of equation for all the dependent variables was a specification with the following set of explanatory variables: base year distance to highway, change in distance to highway, sewered vacant land, total vacant land, and -- for housing construction -- residential vacancy rate. Attempts to include additional variables to account for more complex relations, such as competition for land and co-location or agglomeration, yielded ambiguous results. The simpler specifications therefore were chosen for final regressions.

Heteroscedastic errors remained in all of the equations. This problem clearly was caused by the large proportion of small districts within each regional sample. In Washington, for example, more than half of the districts fell within the 100 square miles composing the urban core. While there is no theoretical reason why the equations should not apply to these small geographical units, the actual data for land use changes in these areas are very uneven. Statistically, these lumpy data reduce the efficiency of the regressions.

For this reason, we used weighted least squares (WLS) to correct the bias. WLS weights unreliable observations less than the more reliable ones, and therefore allows the regression to estimate parameters more accurately. All variables were weighted by multiplying by district size. Thus, the larger districts were emphasized more than the small districts. The absolute value of the residuals from this test were then regressed on district size to determine whether any correlation remained. The coefficient for district size was highly significant and positive, indicating that this procedure over-corrected, leaving large districts with large residuals. A second WLS regression was performed using the square root of district size as a weight. This time the residuals and district size were uncorrelated. Accordingly, this weight was selected as appropriate for single-family housing. A similar test with multi-family construction showed that the same weight was appropriate. The weight for industrial land use was total land in the district, while no weight was necessary for commercial land use.

An additional (unshown) set of regressions were performed using these same variables defined as district shares of regional totals rather than as actual district values. The dependent variables thus were district percentages of total regional land use changes. The tests were made to establish empirically whether such a specification would improve the explanatory power or significance of the regressions. However, the results almost exactly duplicated those of the regressions presented below in terms of both t statistics and R^2's.

1. Single-Family Housing Construction

The final equation, in a difference form, for single-family units constructed is shown in Table 16. The equation with the pooled data shows significant coefficients for the independent variables with the direction of impact conforming to expected behavior. The further an area is from a highway in the base year the less development occurs; a decrease in distance to a highway during the forecast period increases development of single-family units. Availability of vacant land and sewer service increase single-family construction, with sewer service having a larger impact. A slow housing market in the area in the base year, as measured by a high vacancy rate, discourages development of new single-family units.

2. Multi-Family Construction

The final equation, in difference form, for multi-family construction is given in Table 17. In the pooled sample, all variables are significant with appropriate signs. The coefficient of the vacant land term has a negative value for multi-family units. The negative sign on the vacant land supply variable can be interpreted as indicating lack of demand in areas with larger amounts of vacant land, that is, in areas with little access and many acres of vacant land.

3. Commercial Land Conversion

Results for commercial land development are shown in Table 18. The same pattern emerges as for the residential equations. The large constant for the Boston equation, and Boston dummy variable in the pooled equation, reflect the inclusion of additional land uses in the Boston data for commercial land. However, the coefficients of various parameters for Boston fell within an acceptable range compared with other regions, so that no major bias (aside from the value of the constant) was apparent.

In the pooled equation, change in distance to highway is not significant but has the appropriate positive sign.

Table 16. ESTIMATES OF SINGLE-FAMILY RESIDENTIAL CONSTRUCTION[a]

Change in Units within District =

b_2(Base Year Distance to Highway) + b_3(Change in Highway Distance)

+ b_4(Base Year Vacant Land) + b_5(Base Year + Change in Sewered Vacant Land)

+ b_6(Residential Vacancy Rate) + b_7(1/Square Root of Total Land) + Constant

+ b_8(Dummy Variable for Metropolitan Areas)[d]

								b_8		
Coefficient	b_2	b_3	b_4	b_5	b_6	b_7	Constant	Boston	Minneapolis	Washington
Average Value	-0.74	75.2	0.024	0.074	-19.3	-3.38×10^4	951	-73	218	830
T-statistic[b]	-4.39	3.06	2.82	5.37	-3.57		4.40	-0.52	1.51	5.19

Coefficient of Determination (R^2) = 0.49

F-value[c] = 51.87

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[a] Pooled data for Boston, Denver, Minneapolis, and Washington. Total number of districts, N=495.
[b] T-statistics at the 1%, 5%, and 10% levels are 2.326, 1.645, and 1.282, respectively.
[c] The F-value at the 1% confidence level is 2.37.
[d] The regional adjustment for Denver is implicit in the value of the constant.

Table 16 (continued). PARTIAL CORRELATION COEFFICIENTS FOR SINGLE-FAMILY CONSTRUCTION BY INDIVIDUAL METROPOLITAN AREA
(Equations Weighted by the Square Root of Total Land)

	Base Year Distance To Highway (miles)	Change in Distance To Highway (miles)	Base Year Vacant Land (acres)	Base Year Plus Change in Sewered Vacant Land (acres)	Base Year Total Residential Vacancy Rate	Constant
Boston	-0.15	0.11	0.49	0.23	-0.02	0.43
Denver	0.18	0.04	0.31	0.52	0.39	0.40
Minneapolis-St. Paul	0.15	0.20	0.33	0.64	-0.02	0.49
Washington, D.C.	0.42	0.07	0.56	0.49	0.03	0.66
Pooled	0.25	0.09	0.44	0.58	0.13	0.50

	Dummy Variables		
	Boston	Minneapolis	Washington
Pooled	-0.06	0.22	0.50

Table 17. ESTIMATES OF NEW, MULTI-FAMILY RESIDENTIAL CONSTRUCTION[a]

Change in Units within District =

b_2(Base Year Distance to Highway) + b_3(Change in Distance to Highway)

+ b_4(Base Year Vacant Land) + b_5(Base Year + Change in Sewered Vacant Land)

+ b_6(Residential Vacancy Rate) + b_7(1/Square Root of Total Land) + Constant

+ b_8(Dummy Variable for Metropolitan area)[d]

								b_8		
Coefficient	b_2	b_3	b_4	b_5	b_6	b_7	Constant	Boston	Minneapolis	Washington
Average Value	-0.52	52.9	-0.11	0.050	-17.0	-6.96×10^4	2130	200	688	1380
T-statistic[b]	-2.24	1.59	-7.98	3.05	-2.63		6.95	1.17	3.95	7.21

Coefficient of Determination (R^2) = 0.34

F-value[c] = 24.95

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[a] Pooled data for Boston, Denver, Minneapolis, and Washington. Total number of districts, N=495

[b] T-statistics at the 1%, 5%, and 10% levels are 2.326, 1.645, and 1.282, respectively.

[c] The F-value at the 1% confidence level is 2.37.

[d] The regional adjustment for Denver is implicit in the value of the constant.

Table 17 (continued). PARTIAL CORRELATION COEFFICIENTS FOR MULTI-FAMILY CONSTRUCTION BY INDIVIDUAL METROPOLITAN AREA (Equations Weighted by the Square Root of Total Land)

	Base Year Distance To Highway (miles)	Change in Distance To Highway (miles)	Base Year Vacant Land (acres)	Base Year Plus Change in Sewered Vacant Land (acres)	Base Year Total Residential Vacancy Rate	Constant
Boston	-0.11	-0.06	0.04	0.64	-0.15	0.20
Denver	-0.07	-0.03	-0.19	-0.03	-0.09	-0.05
Minneapolis-St. Paul	-0.14	-0.11	-0.30	0.44	-0.18	-0.003
Washington, D.C.	0.06	0.01	0.05	0.22	-0.23	0.34
Pooled	-0.0007	-0.02	0.05	0.35	-0.04	0.24

	Dummy Variables		
	Boston	Minneapolis	Washington
Pooled	0.03	0.05	0.38

Table 18. ESTIMATES OF LAND CONVERSION TO COMMERCIAL USE[a]

Change in Acres within District =

b_2(Base Year Distance to Highway) + b_3(Change in Distance to Highway)

+ b_4(Base Year Vacant Land) + b_5(Base Year + Change in Sewered Vacant Land)

+ Constant + b_6(Dummy Variable for Metropolitan Area)[d]

						b_6		
Coefficient	b_2	b_3	b_4	b_5	Constant	Boston	Minneapolis	Washington
Average Value	-6.20	2.07	0.002	0.011	15.13	147.6	-8.18	26.25
T-statistic[b]	-1.713	0.505	1.906	5.100		11.749	-0.539	1.904

Coefficient of Determination (R^2) = 0.29

F-value[c] = 24.98

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[a] Pooled data for Boston, Denver, Minneapolis, and Washington. Total number of districts, N=495.

[b] T-statistics at the 1%, 5%, and 10% levels are 2,326, 1.645, and 1.282, respectively.

[c] The F-value at the 1% confidence level is 2.37.

[d] The regional adjustment for Denver is implicit in the value of the constant.

Table 18 (continued). PARTIAL CORRELATION COEFFICIENTS FOR COMMERCIAL DEVELOPMENT BY INDIVIDUAL METROPOLITAN AREA

	Base Year Distance To Highway (miles)	Change in Distance To Highway (miles)	Base Year Vacant Land (acres)	Base Year plus Change in Sewered Vacant Land (acres)	Constant
Boston	0.13	0.01	0.32	0.17	(0.50)
Denver	-0.07	-0.13	0.06	0.19	(0.17)
Minneapolis-St. Paul	-0.006	-0.07	0.12	0.64	(0.30)
Washington, D.C.	0.25	-0.008	0.44	0.40	(0.52)
Pooled	-0.02	-0.07	0.14	0.19	0.03

	Dummy Variables		
	Boston	Minneapolis	Washington
Pooled	0.45	-0.12	0.007

4. Industrial Land Conversion

The final equation for industrial conversion with the pooled sample has expected signs for the coefficients of the highway variables (Table 19). Vacant land has a negative sign, as it does in multi-family housing, but is of lower significance. Sewer service is positive and significant in the pooled sample. It should be noted that the linear equation for industrial land was weighted by total land rather than by the square root of total land, as the residuals were more properly distributed in the former weighting. To the extent that the industrial base within each city consists of differing industries, one would expect that the slopes of the independent variables would differ among cities, making estimation of a generalizable industrial equation difficult. The relatively poor fit of the pooled equation ($R^2 = .17$) is indicative of this problem.

It should be noted, however, that both commercial and industrial land use data probably suffer from substantial measurement errors. If these errors are random, they will reduce the quality of the statistical fits, but will not bias parameters. If this is the case, the coefficients for the highway and sewer variables will reflect marginal influences of these factors, even if the overall statistical fit is poor.

5. General Discussion of the Regression Equations

When the final equations are compared with the initial set of hypotheses concerning the influence of public investments and other local factors on land use, some revision of the original hypotheses is necessary. Most surprising, perhaps, is the sensitivity of single-family housing construction to both highway and wastewater facilities. The concensus of previous studies is that highways do not effect strongly single-family residential land use. However, most of these studies investigated effects in relatively small areas within a small (1 to 2 miles) distance from new highways. The regression equation for single-family housing implies that new highways affect construction in areas much further away, and that this influence is consistently measurable for larger study districts. An area need not be bisected by a highway to be affected; a change in distance to highway from 10 to 5 miles (implying that the new highway is still 5 miles away) may have a major impact on single-family housing construction.

The substantial influence of wastewater facilities on single-family housing is not surprising in retrospect. Most single-family construction during the 1960's took place on small lots, making public sewers a substantial advantage, if not a necessity. The correlation between sewer service and construction may be a result of coordination between public officials and private developers rather than a simple cause-effect relationship.

Table 19. ESTIMATES OF LAND CONVERSION TO INDUSTRIAL USE[a]

Change in Acres within District =

b_2(Base Year Distance to Highway) + b_3(Change in Highway Distance)

+ b_4(Base Year Vacant Land) + b_5(Base Year + Change in Sewered Vacant Land)

+ b_7(1/Total Land) + Constant + b_8(Dummy Variable for Metropolitan Area)[d]

							b_8		
Coefficient	b_2	b_3	b_4	b_5	b_7	Constant	Boston	Minneapolis	Washington
Average Value	-17.2	19.4	-0.002	0.005	-25.0×10^4	175	-29.1	-93.8	8.46
T-statistic[b]	-3.68	3.61	-1.25	2.14		4.77	-0.89	-3.05	0.24

Coefficient of Determination (R^2) = 0.17

F-value[c] = 12.63

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[a] Pooled data for Boston, Denver, Minneapolis, and Washington. Total number of districts, N=495.

[b] T-statistics at the 1%, 5%, and 10% levels are 2.326, 1.645, and 1.282, respectively.

[c] The F-value at the 1% confidence level is 2.37.

[d] The regional adjustment for Denver is implicit in the value of the constant.

Table 19 (continued). PARTIAL CORRELATION COEFFOCIENTS FOR INDUSTRIAL DEVELOPMENT BY INDIVIDUAL METROPOLITAN AREA
(Equations Weighted by Total Land)

	Base Year Distance To Highway (miles)	Change in Distance To Highway (miles)	Base Year Vacant Land (acres)	Base Year Plus Change in Sewered Vacant Land (acres)	Constant
Boston	0.16	0.11	0.24	-0.04	0.22
Denver	-0.42	0.08	0.66	0.76	0.62
Minneapolis-St. Paul	-0.34	0.02	-0.32	0.11	-0.22
Washington, D.C.	0.53	0.27	0.63	0.54	0.69
Pooled	0.03	0.08	0.07	0.22	0.19

	Dummy Variables		
	Boston	Minneapolis	Washington
Pooled	0.08	-0.05	0.18

The hypothesis that intensive development -- multi-family, commercial, and industrial -- is more sensitive to public facilities than single-family housing is not supported by the statistical results. Effects of highways and sewers on single-family and multi-family dwelling units are roughly equivalent in magnitude. While commercial and industrial development are measured in different units (acres), their relative sensitivity to investments (see below) is of the same order as for housing. This similarity may be caused in part by the use of distance to highway variables in the regressions. The literature suggests that intensive land uses are strongly affected by "pockets" of accessibility -- interchanges and virtual contiguity to highways. "Distance to highway" measures do not properly reflect detailed variations in distances to highways at the lower range (e.g., one mile or less) of highway access. It seems possible that intensive construction activities implied by the coefficients for a 10 square mile district would occur in fact in small subareas having very high accessibility. Thus, for example, a new highway might cause increases of 500 dwelling units for both single- and multi-family housing. But while single-family units might be constructed throughout the district, the multi-family units may be concentrated in complexes near interchanges or be contiguous to the highway. Projected impacts for commercial and industrial land use changes can be given the same interpretation.

It is evident that the equations account for residential construction more fully than for commercial and industrial land conversion. This is no doubt caused in part by the fact that more factors enter in commercial and industrial location decisions. It is also true, however, that land use by businesses is inherently difficult to measure with precision. It is likely that the data contained substantial noise caused by measurement errors which reduced the statistical fits for commercial and industrial development.

There is no clear explanation for the values and signs of the dummy variables in the pooled regressions. They do not correspond to regional growth vectors, mean district growth vectors, or any other intuitive regional differences. It seems likely that the dummy variables are representing a complex combination of these factors as well as correcting for parametric differences among explanatory variables across regions.

Coefficients of determination for the regressions are modest, ranging from 0.17 to 0.49. This is largely a reflection of the extreme simplicity of the specification and, by itself, should not be viewed as a drawback. However, when coupled with the parametric instabilities of the equations -- particularly for the highway and wastewater policy variables -- it does raise questions about the interpretation of findings. These issues are discussed more fully in the following section.

6. Chow Tests on the Pooled Data

The pooling of data across metropolitan areas raises a question concerning the interpretation of the final parameters. If relationships between explanatory and dependent variables are the same for each region, then pooling allows estimation of generally appropriate parameters, with the regional dummy variables helping to explain region-specific differences external to the equations. If, on the other hand, parameters vary from region to region, then pooling allows estimation of *average* rather than general relationships.

Regression of individual regions show that coefficients do in fact vary from region to region, in some cases substantially. To test formally how much of this variation was caused by different parameters rather than random noise in the data, Chow* tests were performed on the pooled and unpooled regression residuals. The Chow test involves construction of an F statistic to test the (null) hypothesis that two sets of coefficients are equal. The F statistic takes the following form:

$$F = \frac{((\text{Pooled Residuals})^2 - (\text{Unpooled Residuals})^2)(1/\text{d.f. pooled-d.f. unpooled})}{((\text{Unpooled Residuals})^2)(1/\text{d.f. unpooled})}$$

It may be noted that the Chow test does not allow confirmation of the null hypothesis that coefficients from pooled and unpooled regressions are equal. Rather, it provides a probability that the two sets of coefficients are *not* equal, i.e., that the null hypothesis is incorrect.

Chow tests were run with both unweighted and weighted specifications. According to these results, we may reject the hypothesis that all coefficients are equal across the four metropolitan regions at the five percent confidence level for all expressions (except the unweighted, multi-family housing equation). In view of these results, some additional discussion of the pooled coefficients and their meaning is necessary.

In reviewing the regression equations, by far the greatest variations in parameters across regions occur for the two highway variables and vacant land. It seems that in some regions and for some types of development, highway investments did not play a particularly important role. Yet in the pooled regressions, base year distance and change in distance to highways have the correct signs and are significant. It is possible that many of the t statistics and some coefficients for individual regions were biased by intercorrelation. However, in the pooled sample, the coefficients are quite stable in spite of continuing collinearity.

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* See Chow, Gregory C., "Tests of Equality between Subsets of Coefficients in Two Linear Regressions," Econometrica, 28, 1960, pp. 591-605.

Vacant land poses a more serious problem, since in some instances coefficients in different regions had opposite signs and were statistically significant. Clearly in this instance the pooled regressions averaged these opposing effects. The fact that the multi-family equation, in which vacant land had a consistently negative effect, was the only one to pass the Chow test suggests that the vacant land coefficient is the principal difference among pooled and unpooled parameters for the other equations. The ambiguity of vacant land as an indicator of lack of demand (development pressure) is disappointing.

In addition to the above problems, the variability in the sewered vacant land parameters deserves mention. While this parameter was positive and highly significant in almost all regressions, it ranged an order of magnitude in size from region to region. Such instability reflects the influence of factors not represented in the specification and suggests that the pooled regression parameters do not necessarily reflect the "true" population parameter. Only more complete specifications attempting to represent exogenous forces can determine the generality of the pooled regression parameters.

Overall, the failure of the pooled regression coefficients to pass the Chow test is not surprising. It is unlikely that public investments would have precisely the same marginal influence in all areas. The results must be considered as average rather than general relations. The confidence intervals for the highway and sewer service variables are averages which include variations from region to region in the sample.

7. Equations with Forecast Year Stocks as Dependent Variables

As a final adjustment, the equations were recast with forecast year stocks of dwelling units or acres of land use as dependent variables and base year stocks as additional explanatory variables. This format is more appropriate for applying the equations, since it helps to insure that any projected land use changes and secondary effects will be evaluated in the context of base year conditions. Clearly the importance of development is a function of existing conditions. Construction of 500 apartment units, for example, has different significance in an area that is largely undeveloped than in an area with substantial stock of apartments.

Quite obviously, the new format with base year stock as an explanatory variable improves the stability and performance of the equations. While this is desirable from a pragmatic viewpoint, it should be recognized that there is no effect on the accuracy of the equations in predicting land use changes. The new format merely changes the base on which the R^2 and F statistics are calculated. All of the additional variation that is explained is attributable to the base year stock variables.

The recast equations are shown in Table 20. There are very modest changes in the previous coefficients, aside from those expected from the change of the numerical magnitude of the dependent variable.

Coefficients for the base year stocks are all highly significant. Of these, only the single-family housing variable has a coefficient smaller than unity. A value of less than unity reflects a tendency for the number of single-family homes in a district to decrease in the absence of other stimuli. This is in accordance with events during the period from 1960-1970, when multi-family housing gained in popularity while many older, single-family homes were demolished or renovated as apartment buildings.

All of the equations except that for commercial land were estimated using Weighted Least Squares, and contain correction terms (i.e., 1/total land or 1/square root of total land) to account for differences in land use caused by district size. For commercial land, WLS was not justified on the basis of heteroscedastic errors. However, we felt that district size might still be an important influence on commercial land, so a similar correction term was added to the specification in the final regression. As the Table shows, this term is consistent with the other equations and is highly significant.

Table 20. ESTIMATES OF FORECAST YEAR STOCKS OF DEPENDENT VARIABLES[a]

Units or Acres[b] in Forecast Year =

b_1(Base Year Units or Acres) + b_2(Base Year Distance to Highway)

+ b_3(Change in Distance to Highway) + b_4(Base Year Vacant Land)

+ b_5(Base Year + Change in Sewered Vacant Land) + b_6(Residential Vacancy Rate)

+ b_7(1/Square Root Total Land or 1/Total Land)[c] + Constant

Value of Coefficient	b_1	b_2	b_3	b_4	b_5	b_6	b_7	Constant			
								Boston	Denver	Minneapolis	Washington
Single-Family	0.944	-0.72	66.3	0.015	0.079	-20.0	-3.59×10^4	1170	1100	1490	2060
T-statistic	44.05	-4.26	2.69	1.63	5.75	-3.72					
Multi-Family	1.012	-0.52	52.7	-0.11	0.050	-16.7	-7.01×10^4	2300	2120	2790	3480
T-statistic	54.67	-2.21	1.58	-7.74	3.06	-2.58					
Commercial	1.402	-6.49	3.98	0.0021	0.0044	-	-1.17×10^4	73.0	21.8	-6.1	27.0
T-statistic	52.98	-2.21	1.19	2.80	2.48						
Industrial	1.154	-7.25	10.7	-	0.0033	-	-13.8×10^4	81.9	75.7	45.4	97.3
T-statistic	36.27	-2.10	2.46		1.52						

	Single-Family	Multi-Family	Commercial	Industrial
Coefficient of Determination (R^2):	0.92	0.89	0.90	0.84
F-value:	533.4	352.5	492.4	[illegible]09.9

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[a] See footnotes a-d of Table 16.

[b] Units for residential categories; acres for commercial or industrial.

[c] Square root of total land for residential categories; total land for commercial or industrial.

Table 20 (continued). PARTIAL CORRELATION COEFFICIENTS FOR 1970 STOCK EQUATIONS

Independent Variable / Dependent Variable	1960 Stock	Base Year Distance To Highway	Change in Distance To Highway	Base Year Vacant Land	Base Year Plus Change in Sewered Vacant Land	Residential Vacancy Rate	Constant
Forecast Year Single-Family Housing	0.92	0.13	0.02	0.25	0.49	0.13	0.5[illegible]
Forecast Year Multi-Family Housing	0.91	-0.10	-0.07	-0.09	0.10	-0.10	0.05
Forecast Year Commercial Land	0.94	-0.03	-0.09	0.08	0.17	-	-
Forecast Year Industrial Land	0.91	0.48	0.22	0.54	0.39	-	0.60

	Dummy Variables		
	Boston	Minneapolis	Washington
Forecast Year Single-Family Housing	0.25	0.24	0.36
Forecast Year Multi-Family Housing	0.15	-0.03	0.16
Forecast Year, Commercial Land	0.49	-0.12	0.008
Forecast Year, Industrial Land	0.04	0.46	0.23

III. CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

A. IMPLICATIONS OF THE FINDINGS

In broad terms, the econometric results have three important implications. The first is public investments in transportation and wastewater facilities have identifiable and measurable effects on urban growth. As an hypothesis, this statement is accepted without issue by most planners and analysts. The present study supports this hypothesis with empirical evidence and partial quantification of effects.

Another implication is that highways and sewer facilities, on average, are associated with relatively modest changes in urban development patterns. The results suggest that if impacts are measured as a proportion of land use change attributable to public investments, sewer lines are responsible for some 5 to 15 percent of new development over a 10 year period, and highways for approximately the same amount. The maximum elasticity of construction to sewers was for single-family housing. The value, calculated at the mean, is about 0.5. The maximum elasticity for change in distance to highways was about 0.2. Neither of these elasticities is particularly large.

It is crucial to recognize, however, that while average impacts are small, a significant portion of impacts are more substantial. Thus, for example, while the average sewer investment may lead to an increase of about 15 percent in single-family housing construction, the largest 10 percent of sewer investments (measured in terms of sewered vacant land) may be associated with increases of 40 percent and more.

The results support what seems intuitively correct in this instance. The majority of public investments have modest (but still significant) impacts on urban growth. However, when major investments are made in areas with appropriate market conditions, the impacts may be substantial. For example, a new highway traversing many portions of a region will cause minor changes in most parts of the region. Only districts which were previously inaccessible to highways are likely to experience substantial secondary effects. Hence, a given highway is likely to cause a variety of small, moderate, and large impacts in different portions of a single metropolitan area.

B. LIMITATIONS

In practical terms, perhaps the most severe limitation of the regression equations is the variability of parameters and of the residual variation from region to region. These problems, discussed in Section II, create difficulties in application of the regression equations without situation-specific re-estimation of the parameters. Of course, historically derived regression equations, no matter how accurate in a statistical sense, cannot be trusted as a sole source of information for decision-making. Nevertheless, the instability of policy variables from region to region, and the low coefficiencts of determination, imply that the equations should be applied even with greater caution than is normally the case.

From another point of view, the results are quite encouraging. In view of the simplicity of the underlying model, the stability of parameters and the values of R^2's are acceptable and, in some instances, impressive. The results suggest that basic forecasting techniques of this structural type are possible, given a more complete specification. To reach a better specification, some problems only briefly addressed in this work require a more thorough examination. In this context, the limitations of the study may be summarized as follows:

- the issues of timing and feedback between the capital planning process and development were not investigated;

- the various mechanisms available to policy-makers for controlling urban growth and secondary effects received only a small amount of study;

- the analytic techniques derived from the research were not integrated into the planning process as a whole; and

- several promising extensions and refinements of the regression equations were beyond the scope of the project.

These limitations are discussed more fully in the following section.

C. AREAS FOR FURTHER RESEARCH

1. Timing and Feedback in Planning and Development

The principal issues of timing and feedback are planner-developer interactions and lags (or leads) in the relationships between development and planning. Developers not only respond to the availability of existing and planned public service facilities, but influence planning decisions about where and how much to extend public facilities. This interaction makes it difficult to establish whether development is an "effect" caused by public investments. What is needed is a more detailed understanding of these interactions and their timing.

This area of research may be subdivided into several specific questions:

- How do developers respond to capital planning?
- How (or to what extent) are capital plans formulated in response to pressures for development?
- What are the response times for these interactions?

a. Developer Response -

Statistical analyses have established a correlation between development and the construction of new public facilities. This relationship, however, might be more appropriately represented as a response to investment plans rather than actual construction of facilities. In evaluating the lag between investment decisions and development, it may be more accurate to use the date of planning approval or public announcement of plans rather than dates of construction activities. Additionally, the length of time over which developer response occurs remains uncertain.

b. Developmental Pressure for New Facilities -

The phrase "developmental pressure" is frequently used to describe a situation in which high levels of demand and/or attractive locational characteristics cause developers to request or petition government officials for the necessary facilities and permission to construct new structures. Developmental pressure may cause spot zoning variances, altered master plans, and extensions of public services and facilities into previously unserved areas. However, little is currently documented about the frequency or extent to which capital plans are influenced by such pressure.

c. Response Times -

Several timing scenarios are possible for planning-development interactions. Developers may purchase land without access to public facilities, subsequently attempt to convince authorities to provide facilities, and if successful, proceed with development. Alternatively, developers may purchase land after plans for extending facilities have been approved but prior to their construction. Finally, developers may purchase land and initiate construction after new facilities are in place. The relative frequency with which these alternatives occur has important implications for the planning process, occurrence of windfall profits, and equitable financing of capital facilities.

2. Mechanisms for Controlling Development

The traditional and most common mechanism for controlling development and land use in the United States is zoning. A large percentage of cities have prepared master plans containing long range guidelines for land use, with zoning specified as the means of insuring that growth conforms to plans. However, in a growing number of metropolitan areas it has become obvious that zoning is not an adequate mechanism for control of land development, at least not as it is usually administered. Variances are readily obtainable. Local jurisdictions often rush to permit commercial or industrial development to increase tax bases in spite of the fact that such developments violate approved master plans. Recently, new control mechanisms such as moratoria on sewer hookups or building permits have been introduced. These controls have had a variety of consequences on housing prices, local economies, and development, most of which were not fully anticipated. While public controls on land use appear in theory to offer the best means of environmental protection, a more complete understanding of the relationships between controls, development, and local socioeconomic conditions is essential for designing appropriate policies.

The central research questions are:

- To what extent has zoning served historically to control development?
- What are the implications of alternative control measures?

The issue of enforcement is an important one, because any form of direct land use control, such as zoning, could be effective if it were rigorously enforced. But this implies a lack of change over time, which may be more questionable than freely changing land use controls, since land market conditions and requirements for space are constantly changing in urban areas. Research should be aimed at determining the frequency of zoning variances, criteria by which they are made, and consequences of rigid zoning. In addition, the consequences of alternatives to zoning such as phased growth strategies should be explored to the extent that data permit.

3. Extensions and Refinements of Current Techniques

The regression equations developed as forecasting techniques for secondary effects contain several limitations which might be removed through further research. The limitations are a result of the approach used in estimating equations and of weaknesses in our understanding of the processes leading to urban development.

One of the principal criteria for the equations was simplicity of form to insure ease of use. This criterion should also apply in future research. While results of other efforts involving complex structural forms and multiple equation systems should, of course, be utilized, the emphasis in this project is to be on reduced forms and simple recursive systems.

4. Variations in Relationships Across Regions

As noted previously, the substantial variation in relationships across metropolitan regions constitutes a major stumbling block in the development of general forecasting techniques. Increased understanding of the causes of this variation is an important goal of further research.

While some interregional variation occurred for all parameters, the most significant instabilities involved the highway variables, sewer service, and vacant land. Problems with the highway variables no doubt were principally a result of the extreme simplicity of the measure. Future efforts should be directed toward improving the variables employed. For sewer service, on the other hand, improved results should follow from a more complete specification of exogenous factors, such as soil characteristics, topography, and local regulations, which influence the importance of public sewer service to developers. In addition, further investigation of combined capacity-service area measures and treatment availability measures is justified.

Problems with the vacant land variable appear most severe. The variable is ambiguous in representing both supply and demand (or lack of demand). Perhaps the most promising approach is to include a more thorough specification of demand factors, so that vacant land availability will be limited to a representation of supply.

5. The Influence of Accessibility

Substantial ambiguities were encountered in determining how accessibility and new transportation investments influence development. Coefficients for accessibility and proxy variables showed little stability, changing signs and levels of significance across metropolitan areas tested. There are several possible explanations, both theoretical and practical.

The response of developers, particularly in the residential sector, to accessibility may be strongly nonlinear. While workers require access to their place of employment, they may satisfy this preference rather than optimizing it. If this is true, then we should expect that for values of accessibility below or above some intermediate range, little correlation would be found between access and development. The question of nonlinearities was not fully investigated in our statistical analyses.

It is also to be expected that different socioeconomic groups will respond differently to changing accessibility. According to Kain, an important variable is the value attached to (travel) time, in addition to transport costs. Several studies, however, have found positive correlations between income levels and travel time to work. While this does not contradict Kain's theory, it does suggest that other constraints prevent high income workers from reducing journey-to-work travel times. In general, little systematic research has been directed toward the transportation preferences of various socioeconomic groups. Observed trip distributions, a typical proxy for travel demand, do not necessarily conform to actual preferences.

The question of preferences points to a related practical problem in defining accessibility. The most common approach is to measure access by using a gamma function or friction factor representing observed trip distributions. In essence, the gamma function expresses a probability that workers will travel some given time. This distribution function, however, reflects observed trips rather than preferences, and therefore usually shows a higher probability that people will travel 15 to 20 minutes than 5 minutes. This approach could be improved if the gamma function reflected instead the probability of "willingness" to travel a specified time for a specified group. The influence of access would then be isolated from other factors.

Clearly, "willingness to travel" is not a fixed characteristic, but rather varies over time and in different areas. An investigation of these variations would represent a very substantial long-term research program in itself. In the short term, however, important insights might be gained by investigating the response of different household categories and of developers to access, using existing measures. In particular, disaggregation of development into more detailed categories -- residential by density, industrial and commercial by type of business -- should allow refinements in the existing equations. Ongoing studies by the National Bureau of Economic Research provide tentative evidence that such disaggregation is very helpful for residential development.

Breaking down development into more detailed categories would also provide the means for estimating public costs of development in terms of new facilities and services. This would allow planners to design and evaluate policies for encouraging efficient growth patterns in a financial sense.

6. Finer Geographic Scale

The second major potential refinement of the equations is reduction in the size of the geographic areas to which they may be applied. Greater detail would provide more useful information for municipal and environmental planners.

It must be recognized, however, that at some point, detail becomes less useful because of lower accuracy. The point of diminishing returns is uncertain, but NBER housing studies clearly indicate that trade-off between detail and accuracy. Their regressions for areas smaller than census tracts show low (i.e., less than .25) percentages of explained variation in spite of significant independent variables. The census tract could be a suitable compromise, but some normalization may be necessary to overcome wide variations in the size of tracts.

If the geographic scale is reduced to a census tract level, several new explanatory variables will probably be necessary to maintain acceptable statistical fits. In particular, neighborhood socioeconomic characteristics, structural qualities, and land use policies may be important. In our tests of such variables for areas 10 to 40 square miles in size, they were not consistent in their effect or level of significance, a result which we interpreted as indicating substantial variations for these variables within districts. At the census tract level, however, there should be little internal variation.

To incorporate more detail, the dependent development variables should be disaggregated to represent several densities of residential construction and categories of industrial and commercial development. However, the number of dependent variables may ultimately be minimized by reaggregating residential, industrial, and commercial categories that have similar responses to the explanatory variables.

7. Social Impacts

An important area not explored in our research was analysis of social impacts -- changes in demographic and social features of local populations as a result of public investments. Social impacts may be regarded as arising from land use and housing market changes and therefore as derivative to them. However, in view of their importance for social planning and public policy, the techniques should be extended to address social impacts directly.

It is theoretically feasible to estimate equations for social and demographic conditions in much the same fashion as for land use, with land use changes used as an explanatory rather than dependent variables. Such equations would allow a two-stage analysis in which land use impacts of public investments would be first projected and then used to project social impacts of investments.

Dependent variables for social impact equations should be descriptive of demographic conditions most important to local planners. Among the possible variables are measures of family income or income distribution, age of household heads, family size, and racial mix.

Costs of land and housing are probably important influences of the above variables. Since the original equations provide estimates of changes in stocks of structures and land uses, but not changes in prices or rents, the explanatory variables for the social impact equations should include measures of housing market and social conditions in the base year. In addition, social policy variables concerning housing might be included. Assuming a lagged cross-sectional formulation, such as used for land use, the social impact equations would project demographic changes over a 10 year interval by base year housing market and social conditions, social policies during the interval, and development and land use changes over the interval.

8. Analysis of Developmental Effects in the Planning Process

Research and related studies sponsored by the Council on Environmental Quality in association with other Federal agencies have led to new techniques for evaluating secondary effects and the costs of urban development. There remains, however, the important task of integrating these techniques in the local and regional planning processes. The investigation of secondary effects has established the central role that planning plays in the generation of impacts. Often a simple lack of coordination or cooperation between planning groups is the origin of problems arising from development. Therefore, an attempt should be made to disseminate information concerning the implications of uncoordinated local policies and plans as well as the available means of projecting effects of alternative policies and plans.

The most fruitful short-term product of such an effort would be a manual which discusses secondary effects of public investments and their significance from the viewpoint of the local planner. The urban planning process should provide the context of the manual, and all elements, including transportation, sewerage, water, land use, other services, and financial planning should be addressed. New techniques should be compared with and integrated with more traditional planning methods. The interactions between these elements of the planning process should be discussed in view of their combined influence on urban growth patterns and rates, and the subsequent implications of growth for each planning element.

Since stringent growth controls and no-growth policies are under serious consideration in many parts of the country, these issues should be addressed in the manual. An analysis of ways in which local governments fail to control or guide growth, the impact of sprawl on public services and finances, available mechanisms for controlling or restricting growth, and possible effects of growth control policies should be discussed. In the Washington, D.C. metropolitan area, for example, moratoria have been accompanied by rapidly escalating prices and rents, a lack of moderate- and low-income housing, and growing concern about the continued economic vitality of portions of the region.

It is essential to recognize that as local jurisdictions become aware of the dangers of uncontrolled growth, the central issue in policy design shifts from how to control growth to defining the optimum rate of local growth. In areas that have undergone massive urban development and its consequences, the new generation of planners and policymakers is increasingly confident that future growth can be guided effectively. Their concern now is where, what kind, and how much development would be best for their jurisdictions. Three criteria are evident: (1) environmental, (2) public finances, and (3) housing availability and cost. This project, therefore, should address not only controls and their effects, but the issue of designing optimum growth strategies and managing development to reach objectives.

While these discussions should provide a clear overview of major issues, the central orientation of the manual should be analysis. It should present guidelines for projecting the location, form, and amount of development likely to result from alternative local government actions and socioeconomic conditions. Additionally, methods of estimating the financial consequences of such development in terms of public services and tax structures should be included. Where possible, the manual should also present techniques for projecting impacts of new development on the physical environment, particularly air and water quality.

The guidelines should identify and discuss factors that must be considered in analyses and sources of data. Where feasible, alternative data sources, methods, and techniques should be presented to provide a range of alternative approaches. Rules of thumb and rough approximations that sacrifice some accuracy for simplicity may be very useful to planners and other officials with limited resources or time for such evaluations.

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THE LAND USE SIMULATION MODEL

A. INTRODUCTION

In addition to econometric analyses, a dynamic model was constructed for simulating metropolitan growth, land use changes, and the influence of public investments on these changes. The effort was intended to supplement our statistical work by allowing a more thorough study of the dynamic aspects of secondary effects, including interactions between different forms of urban development and between different portions of a metropolitan area. The dynamic model was also used to evaluate investment-related policies such as sewer moratoria and their impacts, subjects for which inadequate data were available to perform statistical analyses.

The model was tested in an application to the Washington, D.C. metropolitan area. Historical simulations were compared to actual changes within the region to provide an indication of the model's accuracy. Sensitivity analyses were performed to evaluate the importance of parameters in determining system behavior. Subsequently, the secondary effects of major highway and wastewater investments in the Washington, D.C. region during the period 1960-1968 were estimated. The effects and implications of the controversial sewer moratoria imposed between 1969 and 1973 were also evaluated.

The results of these efforts are documented in this Appendix. Section B describes the structure of the model and its computational sequence. Section C presents the results of the model application to Washington, including accuracy evaluations and estimated secondary effects of historical investments. Appendix B provides a complete listing of the model.

B. THE LAND USE SIMULATION MODEL

The land use model simulates changes in population, employment, and land use throughout a metropolitan area, at six-month intervals over a twenty-five year period. The model is programmed in the DYNAMO III[1] simulation language. It was based on previous work on modeling regional growth and land use.[2]

1. Model Structure -- An Overview

The central component of the model, the land use sector, accepts forecasts of regional growth and simulates the distribution of growth among subregional zones. Each zone -- a community, a planning district, or a watershed -- is represented individually in terms of population, employment, and land use. The number of zones is variable; for the Washington test application, a relatively small number, 15, was used.

a. The Land Use Sector -

Land in each of fifteen zones in the Washington area is classified in five major categories: single-family housing, multi-family housing, industrial (including commercial and institutional), vacant (i.e., unused developable land), and undevelopable or recreational land. The sector models interactions between demand and supply for various types of structures, and accounts for changes in stocks, densities, and conversion of vacant land to urban uses.

1. Developers - The most influential private decision-makers in the urban land use market are professional developers. The land use sector reflects this fact; developer decisions about when, where, and what to build are the principal underlying causes of changing land use. While developers necessarily take into account the preferences of their customers concerning locational and structural characteristics, their principal motivation is economic. Hence, developers are modeled as selecting forms of development and locations that maximize profits.

The demand for new structures to which developers respond is determined in part by regional population and employment levels. Developers in the region respond with construction in three categories (business space, multi-family housing, single-family housing) on the basis of the vacancy rate for each type of structure.

2. Relative Attractiveness - Each zone shares in the total regional amount of residential and industrial construction in proportion to its attractiveness to developers relative to all other zones in the region. Five factors influence developer decisions in each zone: accessibilities, levels of wastewater service, availability of land for development, land prices, and local control policies. The importance of each factor varies for different types of development. As construction occurs over time, accessibility, densities, vacant land, sewered land, and land prices continuously change, altering relative attractiveness, and affecting subsequent development.

3. Investments - Highway investments affect development by altering travel times between zones and hence accessibilities to employment and to households. New sewer investments, on the other hand, may affect development by changes in the area served or in the level (capacity) of services, or both. These changes affect zonal attractiveness through

their effect on the availability of land for uses of different intensities.

4. Policies - Local policies affect development in various ways. For example, zoning ordinances can be represented in the model as a density limit or as a change in the availability of vacant land for a particular use. Wastewater policies, such as moratoria, place restrictions on available capacity and sewer service area. Developmental policies, such as building permit restrictions, place limitations on the timing, type, and number of structures that can be started, regardless of the zone's economic attractiveness to developers. Other policies can be specified and evaluated through their impact on local land markets and public service availability.

b. Regional Growth -

Overall regional growth may be entered in the model exogenously. However, the model also includes demographic and industrial sectors for simulating population and employment growth.

1. Population - Three factors directly affect population -- births, deaths, and net migration. A characteristic common to all three is their variation in magnitude among different age groups of the population. This variation makes the age structure of the population an important dynamic element in demographic analysis. Because of the long-term importance of age structure, the population was disaggregated into six age classes, with each class relatively homogeneous with respect to birth, death, and migration rates.

The modeling mechanisms describing birth, death, and migration rates are similar. In each case, regional data are averaged to provide a basic rate, with local or regional influences left implicit. Variations in migration rates are caused by changes in the availability of jobs in the region. Birth and death rates are trended to show shifts caused by forces exogenous to the model.

The principal causal link between the demographic and industrial sectors is through the labor force. Labor force, computed for each age class, forms the supply of workers necessary for industrial expansion. Labor force availability plays an important role in economic growth.

2. Employment - Industry is modeled in accordance with export-base theory. Industries were divided into export and local-serving categories, with the economic base of the region formed around the export businesses. Local-serving industry responds to population and export industry growth. Economic activity is specified in terms of employment.

The growth of export industry in a region is assumed to depend on the relative attractiveness of that region with respect to wage levels and access to raw materials and markets compared to the national average. Increases in government employment were specified exogenously in the Washington model.

Local-serving industries are divided into two groups: household-serving and business-serving. The household-serving businesses supply the needs of ultimate consumers and include subgroups such as retailers, doctors, teachers, local governments, etc. Employment in the household-serving group is proportional to population, with the requirements trended over time. The business-serving industries supply goods and services needed by other businesses and grow in proportion to their growth.

The industrial sector affects population change through employment opportunities. Specifically, changes in unemployment rates were assumed to influence net population migration.

2. Computational Sequence of the Land Use Sector

The focus of the simulation modeling effort in this project was the development of the land use sector. The computational sequence for the land use sector is discussed in this section.

a. Determining Total Construction -

The first step in each computation interval is to transform regional growth into a total amount of construction for the region. To do this, vacancy rates for each of three structure types (business space, multi-family housing, single-family housing) are computed for the metropolitan area as a whole. For business structures, the ratio of existing employee space to total regional employment is computed. Residential vacancy is computed as the ratio of the sum of zonal housing units to housing units required for the current total population.

The vacancy rate computed for each structure type determines additional construction for each type for the region as a whole. This is accomplished by use of DYNAMO's TABLE function, which allows the user to specify any linear or nonlinear relationship between two variables. In this case, the computed "vacancy" ratios determine total new construction starts in the region in each time period as a percentage of existing stocks. New construction is then allocated among zones. The "TABLE" transformation is illustrated in the following figure.

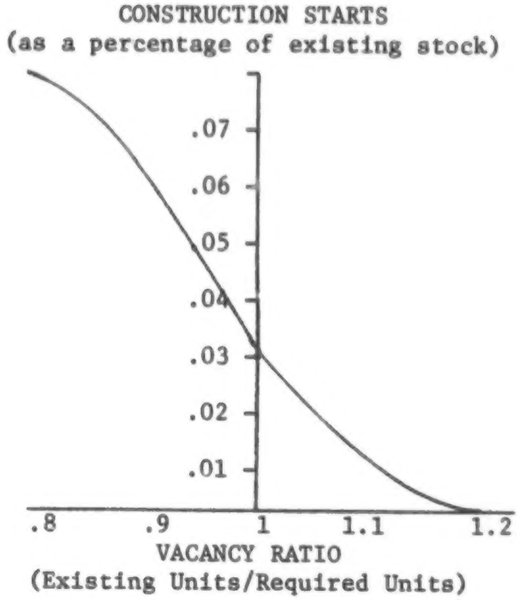


Figure A.1. Effect of vacancy rate on regional construction

b. Geographic Allocation of Total New Construction -

Central equations in the model are those that compute the attractiveness of zones for development. Zonal characteristics which determine attractiveness are updated in every computation interval. The new values reflect development that has resulted from previously perceived attractiveness.

Total regional construction starts of each type are allocated among zones in proportion to each zone's attractiveness relative to all other zones:

$$C_{ijt} = (A_{ij}t / \sum_{z=1}^{N} A_{izt})(\bar{C}_{it})$$

where:

C_{ijt} = construction starts of type i in zone j at time t

$A_{ij}t$ = attractiveness for construction type i in zone j at time t

$\bar{C}_{it}$ = total regional construction starts of type i at time t

N = number of zones

The attractiveness equation is based on an adaptation of land renttransportation cost tradeoff theory:

$$\text{Attractiveness} = f_1(\text{FLD}) \times f_2(\text{AC})$$

where FLD = Fraction of Land Developed (proxy for land price), and AC = Accessibility.

These two effects work in opposite directions, with higher accessibility (higher attractiveness) generally corresponding to a higher fraction of land already developed (lower attractiveness).

The proxy used for land price is the fraction of developed land to total developable land within the zone. A DYNAMO TABLE function specifies a nonlinear relationship between the fraction developed and the attractiveness of the zone to each development type. As can be seen in the Table, attractiveness for low-density, single-family development diminishes more rapidly than multi-family and industrial development.

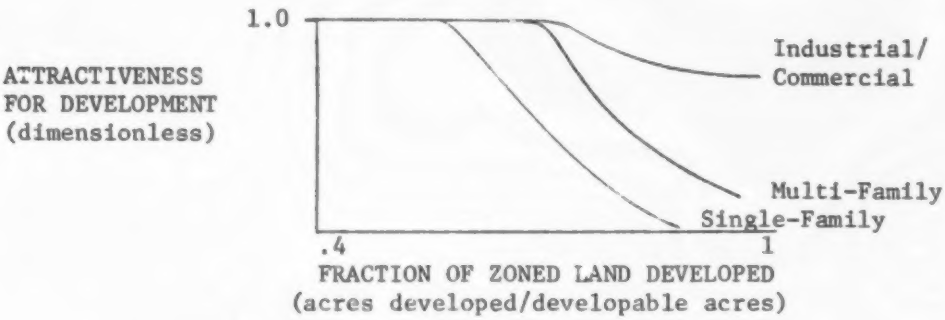


Figure A.2. Zonal attractiveness as a function of land availability

The accessibility to employment or to households afforded by a zone is traded off against "land price." Accessibility differs for industrial-commercial and residential development. For the latter, accessibility means accessibility to employment, representing the sizes of "market areas" from which developers can draw renters and homebuyers. In business development, accessibility means access to households that represent potential customers or labor supply. Accessibilities are computed by calculating travel times between every pairing of zones in the region for a series of points in time. Travel time changes reflect transportation investments (no modal differentiation is currently included in the model). A TABLE function is specified for each type of development to define a nonlinear relationship between interzonal travel times and a variable multiplier that is used in calculating accessibility to employment or residents.

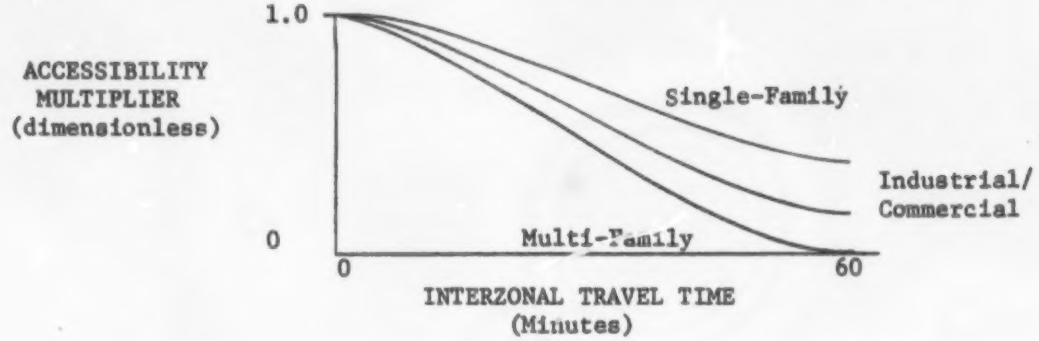


Figure A.3. Effect of interzonal travel times on accessibility

In computing zone A's accessibility to jobs or residents in zone X, the appropriate multiplier, as derived above from the zone A-to-zone X travel time, is multiplied by the number of jobs/residents in zone X. To obtain zone A's total accessibility, the products of these zone A-zone X multiplications are summed across all zones 1...X...N to obtain zone A's accessibility. The same procedure is repeated for every zone and every development type.

$$\text{Access}_{A,D} = \sum_{Z=1}^{N} (\text{TTM}_{D,A-Z} * \text{Activities}_{Z})$$

where:

A = Zone A
D = Development type
N = Number of zones
Activities = Jobs or households, as appropriate
TTM = Travel time multiplier

In order to standardize the "access effect" in the attractiveness equation to the same scale as the fraction of land developed (0-1), each zone's computed accessibility to jobs/households is divided by the total number of jobs/households in the metropolitan area.

Since zone sizes vary, two zones could have the same "attractiveness" based on fraction developed and access, and yet have quite different development potential by virtue of one having a greater absolute quantity of developable land. To adjust for this variation, and to reflect the greater ease of tract assembly in larger zones with more vacant land, the computation of zonal attractiveness is multiplied by the amount of vacant developable land in the zone:

$$\text{Attractiveness} = (\text{FLD} + \text{AC}) * (\text{Vacant Developable Land})$$

The key word is "developable," as the topography of vacant land can eliminate some or all types of development. Topographically undevelopable land and land designated for open space in a zone is subtracted from the zone's vacant land. Developable land also can be constrained by policy, such as zoning restrictions, location of sewer lines, and availability of sewer hookups. Most of these development constraints are represented in the model.

Policies may be imposed on zones within the model structure to limit land availability. Wastewater service plays the most significant role among these policies. Sewer service within each zone is represented in two terms, the capacity afforded the area and the service area of sewer lines. Both are specified exogenously over time, thereby representing wastewater investments in the model. Service areas are represented in acres, and capacities in gallons per day. The specified capacity is that of sewer lines or of treatment plants, whichever is smaller. Land uses and activities that require sewer service reduce the availability of sewered land and treatment/line capacity for subsequent development. The "Sewered Vacant Land" term in the equation below represents the minimum of the vacant service area and the amount of land that could be developed within available capacity constraints. Since not all activities require sewer service, both sewered vacant land and unsewered vacant land are included in the attractiveness formulation, weighted (0 to 1) for each development type:

$$\text{Attractiveness} = (\text{FLD} + \text{AC}) * [(\text{Weight}) * (\text{SVL}) + (1\text{-Weight}) * (\text{UVL})]$$

where:

SVL = sewered vacant land
UVL = unsewered vacant land

Restrictions such as moratoria may be exogenously imposed and removed in any zone at any time to deny or restore availability of sewer service. A moratorium is represented by a multiplier of zero applied for a specified period to any available sewer capacity. This zero multiplier is lagged, however, in order to allow interim construction permitted by any backlog of previously approved sewer hookups or building permits.

Following the initially computed allocation of development among zones, new construction may be subjected to further policy constraints, representing local ceilings on the amount of each type of development, or on the rate of permit issuance. This maximum allowable rate of construction is specified exogenously over time. The amount of each type of construction in a zone at a particular point in time is either the allocated share of regional construction or the imposed ceiling, whichever is less. The ceiling can be specified so as to replicate the enforcement of an adequate public facilities ordinance.

c. Computing Land Use and Densities -

As construction occurs within a zone, accounts of land uses are updated. Total land and recreational and undevelopable land are exogenously specified. Running totals are kept for industrial-commercial and residential land uses. Since the units allocated by the attractiveness function are employment and housing units, a conversion must be made to obtain the additional land (and sewer service area) corresponding to new construction.

Since the categories of residential development in the model are rather broad, they could correspond to different densities for the same type of development in different zones. Therefore, the densities of new single- and multi-family development are specified exogenously over time. This assumes that developers build housing at as high a density as is permitted by local zoning.

Employment densities can be specified exogenously as well. As an alternative, a formulation was tested, with moderate success, that allows employment densities to vary according to zonal land price. As the zonal land price proxy increases, employment density increases (acres per employee decreases) according to the TABLE transformation shown below.

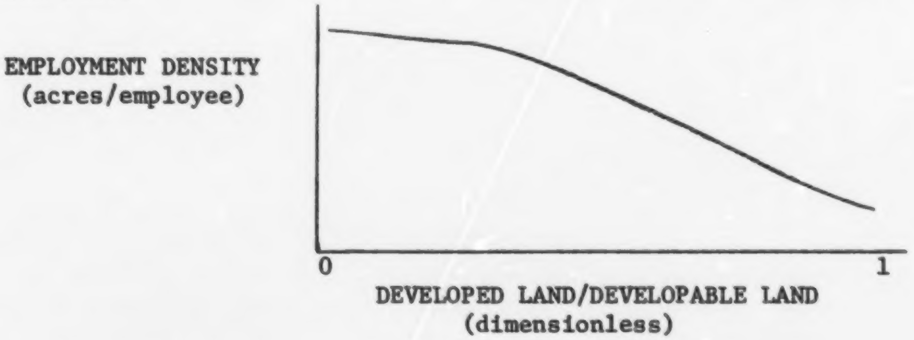


Figure A.4. Form of relationship between employment density and zonal land availability

One such curve was specified for each zone. The shape of the curve remained consistent, but the curve itself was shifted up or down so that the base year employment density in each zone corresponded to the zone's base year fraction of developed land.

Following these computations of new land use, "other development" (local roads, parking facilities) is accounted for in each zone by the multiplication of zonal industrial and residential land use by a fraction (typically .1-.2).

Vacant land, available sewer service, land prices, and accessibilities are subsequently calculated, based upon the newly updated conditions. These form the basis of local attractiveness for further development, and the sequence of land use calculations is repeated in the next computation interval. This continues until the specified forecast year of the simulation is reached.

The values used for parameters in the Washington model are provided in the listing in Appendix B. The following section describes results of the model application.

C. APPLICATION OF THE MODEL TO THE WASHINGTON, D.C. METROPOLITAN AREA

Empirical tests of the land use model were carried out by programming the model with historical data from the Washington regions. Simulated changes in regional growth and land use patterns were then compared with actual changes.

The study period for these tests was 1960-1968. Conditions in 1960 were used to supply input parameters for the model, while 1968 conditions provided a checkpoint for model forecasts. The only exogenously specified changes for that period were highway and wastewater investments and policies. All other phenomena were simulated endogenously.

The following section summarizes the actual changes that took place in the Washington region during the period in question. Subsequently, we describe the geographic representation of the region in the model and evaluate the model's accuracy. Finally, estimated secondary effects of historical investments and policies are presented and assessed.

1. An Overview of Urban Growth in the Washington, D.C. Metropolitan Area (1960-1968)

a. Standard Metropolitan Statistical Area (SMSA) -

The 1960 Washington, D.C. SMSA included the Maryland counties of Montgomery and Prince George's, and the Virginia counties of Fairfax and Arlington. Charles (Maryland), Loudoun (Virginia), and Prince William (Virginia) Counties have been added to the SMSA since 1960.

b. Population -

Between 1960 and 1968, the rate of population growth (37%) in the metropolitan Washington area was among the highest for the nation's largest metropolitan areas.[3] In absolute terms, the population

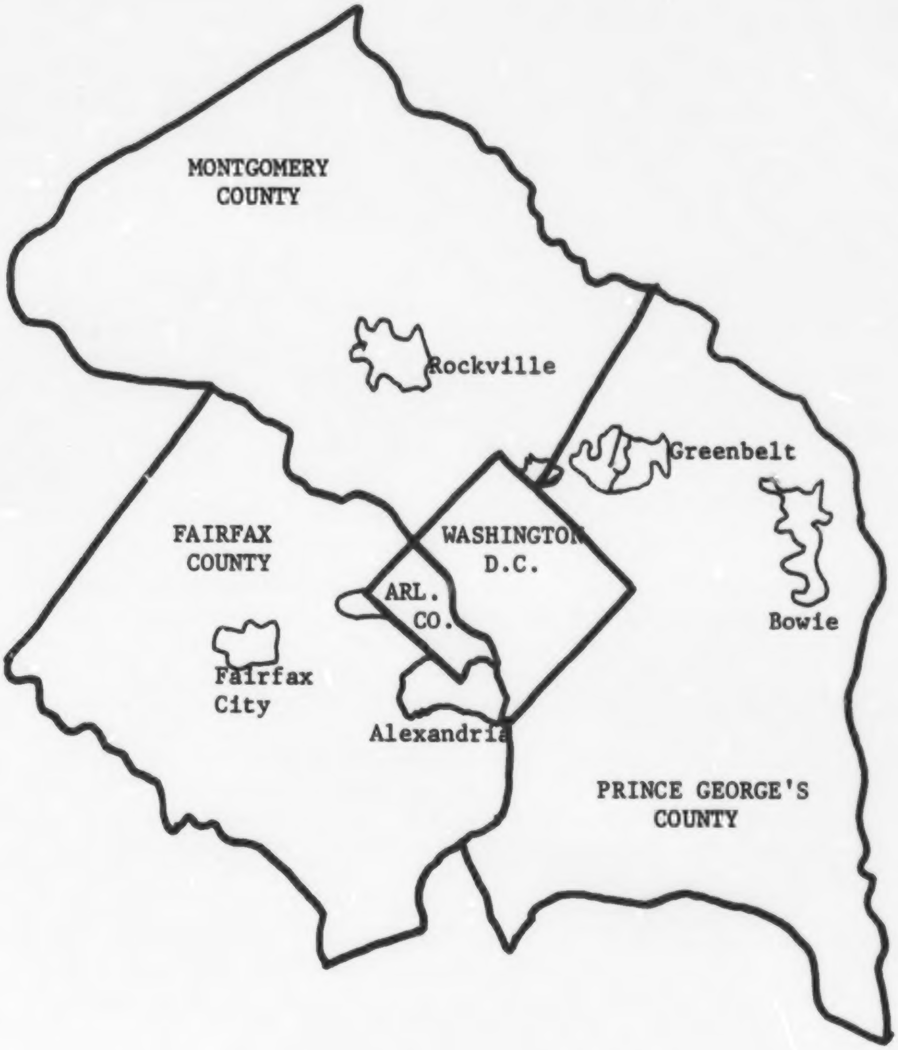

MONTGOMERY COUNTY
Rockville
Greenbelt
FAIRFAX COUNTY
WASHINGTON D.C.
ARL. CO.
Bowie
Fairfax City
Alexandria
PRINCE GEORGE'S COUNTY

Figure A.5. Political jurisdictions

increased from about 2 million to about 2.8 million in the Sixties. Net migration into the Washington area was the greatest of any SMSA.

Table A.1. POPULATION CHANGE[4]

Metropolitan Section[a]	Pop. 1960	Pop. 1970	% Change
Urban Core	169,839	148,000	-12.9
Mature Developed Area	1,073,225	1,126,000	4.9
Developing Area	632,814	1,101,000	74.0
Suburban Area	74,368	203,000	173.0
Low Density Area	82,189	125,000	52.1

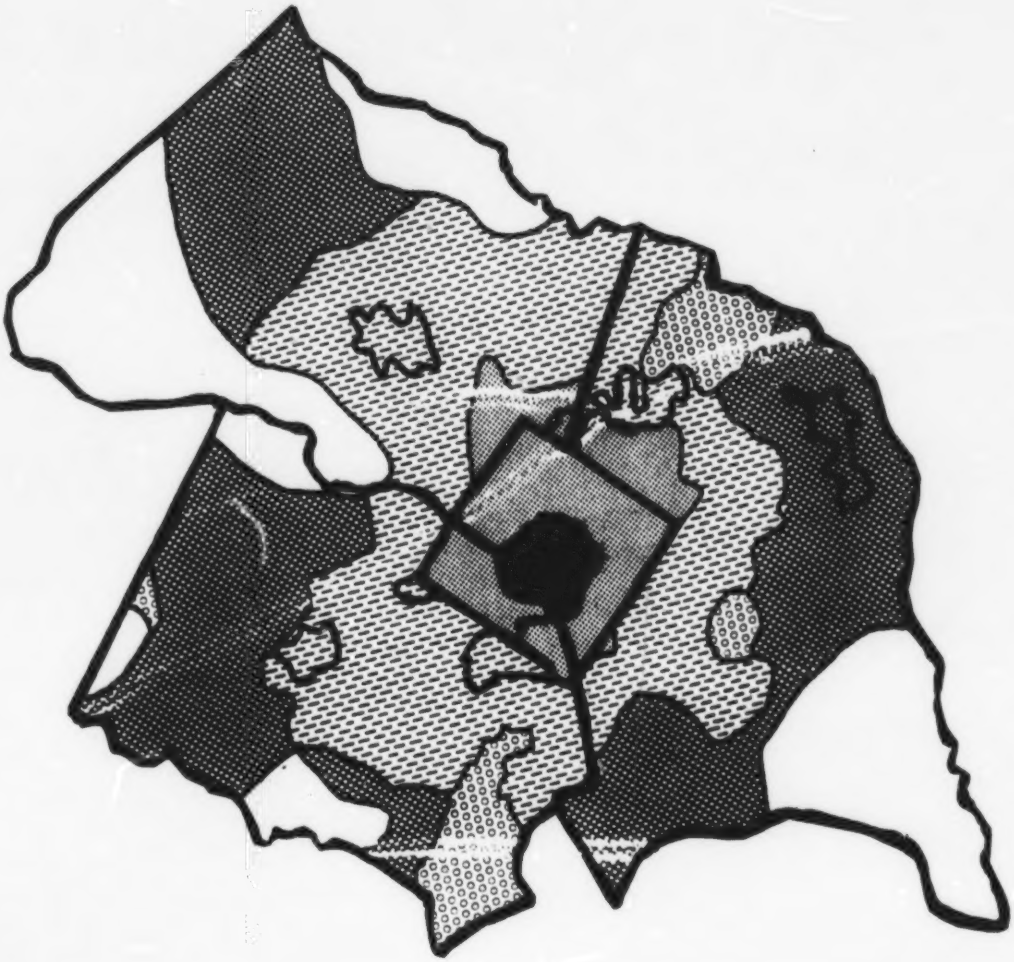
[a] See Figure A.6 for geographic definitions.

c. Land Use -

Trends in land use in the last twenty years have been: increasing specialization of the downtown area; residential expansion and filling in of in-lying areas, followed more recently by "leapfrogging" development; new commercial and employment concentrations; and extension of the Federal establishment into the suburbs. Commercial and industrial growth has extended outward from previously developed areas along major highways such as Route 1 north, Baltimore-Washington Parkway, and Interstate 70. The Capital Beltway has created development nodes at major radial intersections and has facilitated industrial development and growth within its perimeter.[5]

Employment densities continue to be highest in the urban core and have increased in all regions during the period 1960-1968.[6] The results of the Council of Governments 1968 Home Interview Study indicate that the most important single land use is that of "office," which accounts for 39% of all employees. Shopping and consumer services account for 15.5% of employees while industrial land use has 7.8% of all workers.[7]

Residential development has occurred at low densities because of local zoning policies. Prior to 1955, little high density residential development occurred outside of Arlington, the District of Columbia, and sectors of Alexandria. From 1956 to 1959, the bulk of high density residential development was confined to the in-lying suburbs. Very little high density development occurred beyond the present location of the Capital Beltway (see Figure A.7). From 1959 to 1967, high density development increased significantly in both the District of Columbia (due to redevelopment) and suburban areas (garden apartments and town houses.[8] However, net residential density has decreased in the urban core as a consequence of household relocation. Densities in the region



■ Urban Core

▩ Mature Developed

▤ Developing

▦ Suburban

▨ Special Purpose

☐ Low Density

Figure A.6. Current regional development pattern

(From: Areawide Land Use Elements 1972, Metropolitan Washington Council of Governments, July 1972, p. 20.)

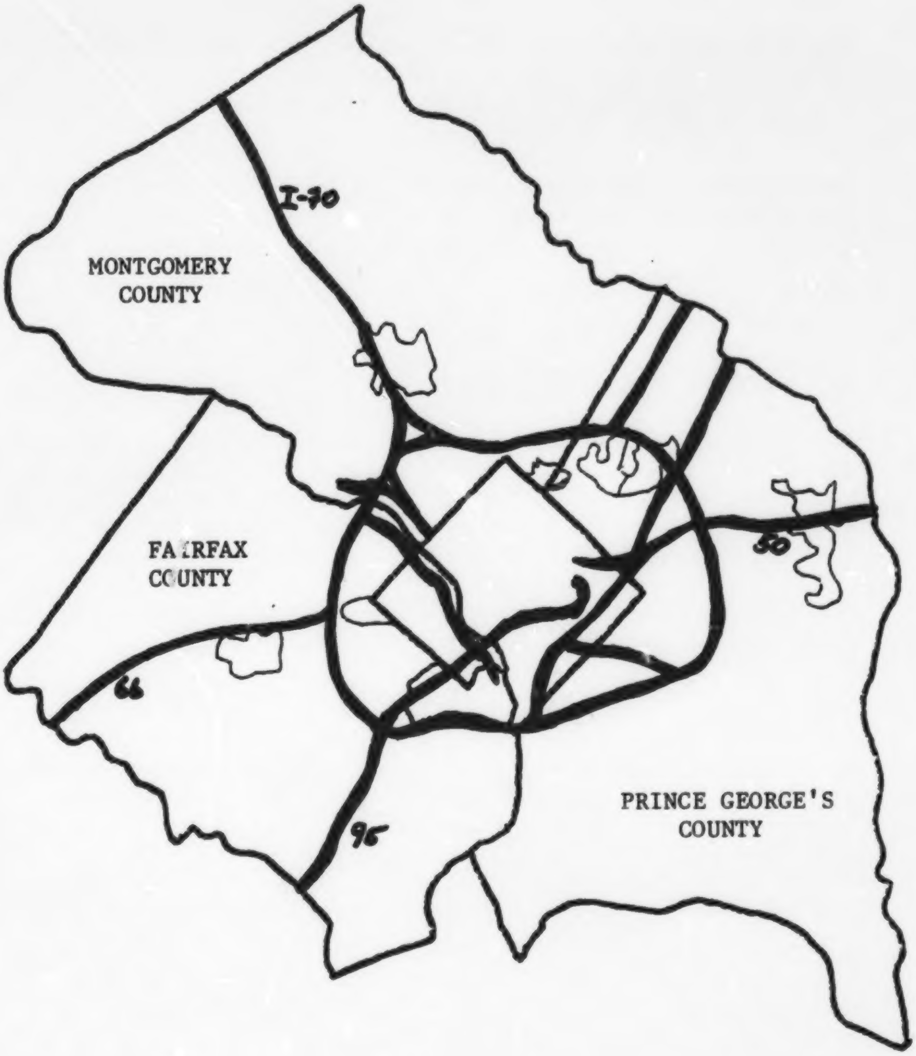

I-70
MONTGOMERY COUNTY
FAIRFAX COUNTY
66
50
95
PRINCE GEORGE'S COUNTY

Figure A.7. Network of major highways

(Adapted from: Areawide Land Use Elements 1972, Metropolitan Washington Council of Governments, July 1972 p.73) as a whole have increased.

Regional open space grew by 24,450 acres between 1960 and 1968. Eighty percent of this increase was in the developing and suburban areas.[9] Open space acquisitions supported regional growth objectives only to a limited extent.[10]

Over 58,000 acres were converted to urban use (residential, commercial, industrial, institutional) in the period 1960-1968. In the core area, an additional 97 acres were converted to urban use; in the mature developed areas, 3,500 acres; in the developing areas, 40,000 acres; and in outlying suburban areas, 15,000 acres. Overall, the increase in urban land use from 1960-1968 was 45%.[11]

d. Economic Characteristics -

The Washington SMSA has an economy based largely on three types of employment: government, services, and retail trade. Other sources are relatively minor, although manufacturing is growing. The economy is relatively stable and incomes are higher than the national average. A sizeable portion of the economy is based on tourism.[12]

The Federal government is the largest single employer in the Washington area: 32.8% in 1964. Employment by major sectors is shown in Table A.2.

Table A.2. EMPLOYMENT BY MAJOR SECTORS

	1964 Est.[13]	1968 Est.[14]	Annual Rate of Growth, 1960-1969[15]
Agricultural	0.2		
Contract Construction	6.1	14.0	3.2%
Manufacturing	5.0		3.3
Trans. & Utilities	4.0		4.1
Wholesale Trade	3.2	17.0	5.4
Retail Trade	13.2		5.8
F.I.R.E.	5.2	27.0	6.0
Services	15.1		7.9
Self-employed	4.9		
Household Workers	3.0		
Federal Government	32.8	39.0	4.0
State & Local Government	6.8		10.8

e. Transportation -

The Washington metropolitan area contains 9,000 miles of streets and highways which accommodate about 33 million miles of travel each workday. Mass transit bus operators supply 121,000 bus-miles of service each weekday, 11% of which occur in rush hours. Eighty percent of peak hour service is in the CBD. While mass transit ridership has leveled off at a constant annual ridership of between 160-170 million passengers, ridership has decreased constantly on a per capita basis.[16]

The opening of the Capital Beltway, I-495, in 1964 was a significant event. The 66 mile long circumferential highway increased accessibility between most parts of the Washington area. For example, the number of workers commuting between Virginia and Maryland increased 133% between 1960 and 1968. During the same period, total jobs in the region increased a little more than a third.[17]

A rail rapid transit system, METRO, is currently under construction.

f. Sewer and Water -

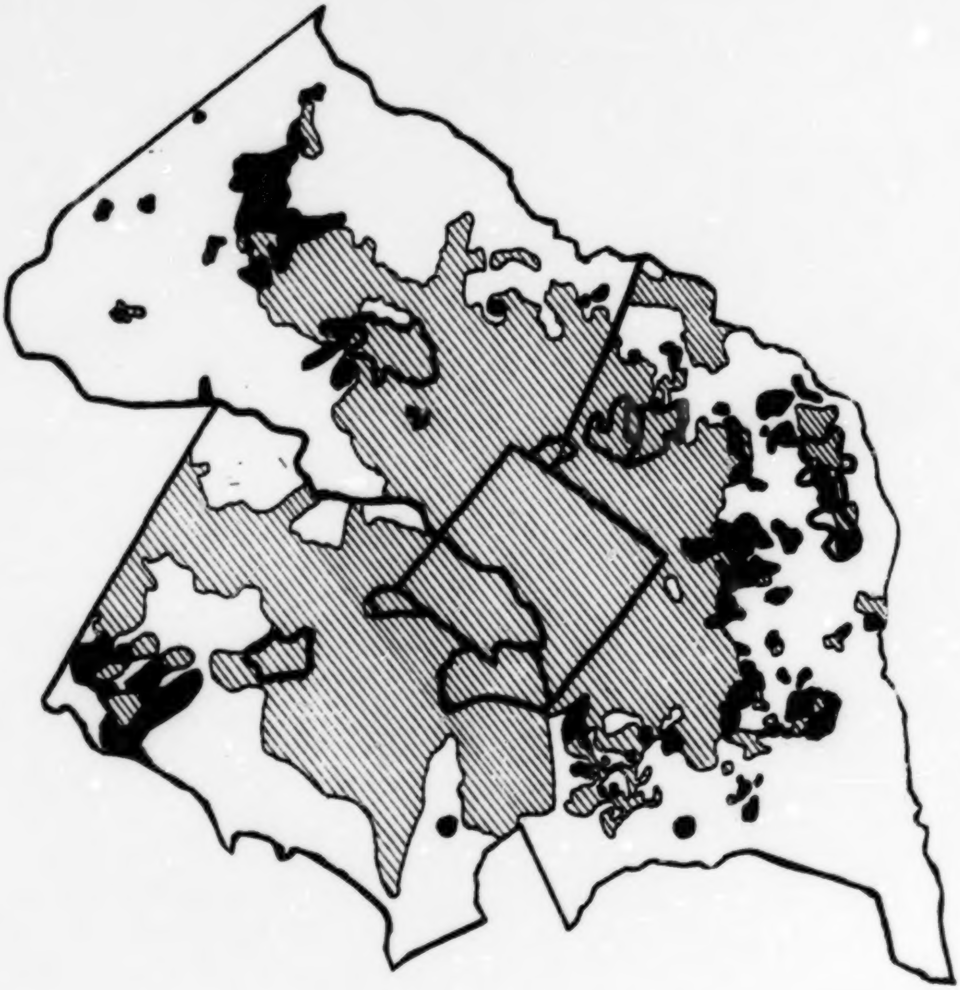
The Potomac is the principal source of water supply for the Washington SMSA. The river is heavily polluted due to silting from the watershed area and runoff from new development areas. Water requirements have increased due to increases in population, per capita consumption and (potential) industrial demand.

The Washington Aqueduct, operated by the Army Corps of Engineers and the District of Columbia Government, provides water to the District of Columbia, Arlington, Falls Church, and military installations in Virginia. It has emergency connections to the Washington Suburban Sanitary Commission.

The Washington Council of Governments (COG), in its 1969 report on Washington,[18] recommended the use of planned sewer extensions and zoning to maintain the integrity of the wedges and corridors concept for regional development.

As of 1970, 93% of housing units in the Washington SMSA had public sewer service. Newly sewered areas in the period 1960-1968 consisted of 419 square miles and were distributed as follows:[19]

Urban Core	0
Mature Developed Area	0
Developing Area	40%
Suburban Area	52%
Low Density Area	6%
Special Purpose Areas	2%



▨ Existing Service Area

■ Future Service Area Expansion

Figure A.8. Water and sewer service area

(From: Areawide Land Use Elements 1972, Metropolitan Washington Council of Governments, July 1972, p. 66.)

Expansion and improvement of waste treatment facilities did not keep pace with extension of sewer service; this imbalance led to sewer moratoria in Montgomery, Prince George's, and Fairfax Counties. The moratoria have resulted in short-term building booms in controlled areas, and intensification of development in outlying areas not subject to moratoria.

2. Boundaries in the Washington Model

The regional geographic boundaries were those of the 1960 SMSA. Fifteen zones were delineated in the Washington area, based on jurisdictional boundaries, data availability, and homogeneity of past development patterns. The zones are shown in Figure A.9. A brief description of each follows.

a. Montgomery County, Maryland: Zones A,B,C,D -

Zone A encompasses the northern portion of Montgomery County. I-70 bisects the zone. The area includes predominantly farm land and low density development. There has been recent commercial development along I-70. Federal employment facilities at Germantown and Gaithersburg are in the zone. Land area is approximately 200 square miles.

Zone B includes the City of Rockville and a section of I-70. Rapid residential development has occurred around the Rockville area. Commercial growth has occurred in the City. Many research and professional firms have located along I-70. Land area, 55 square miles.

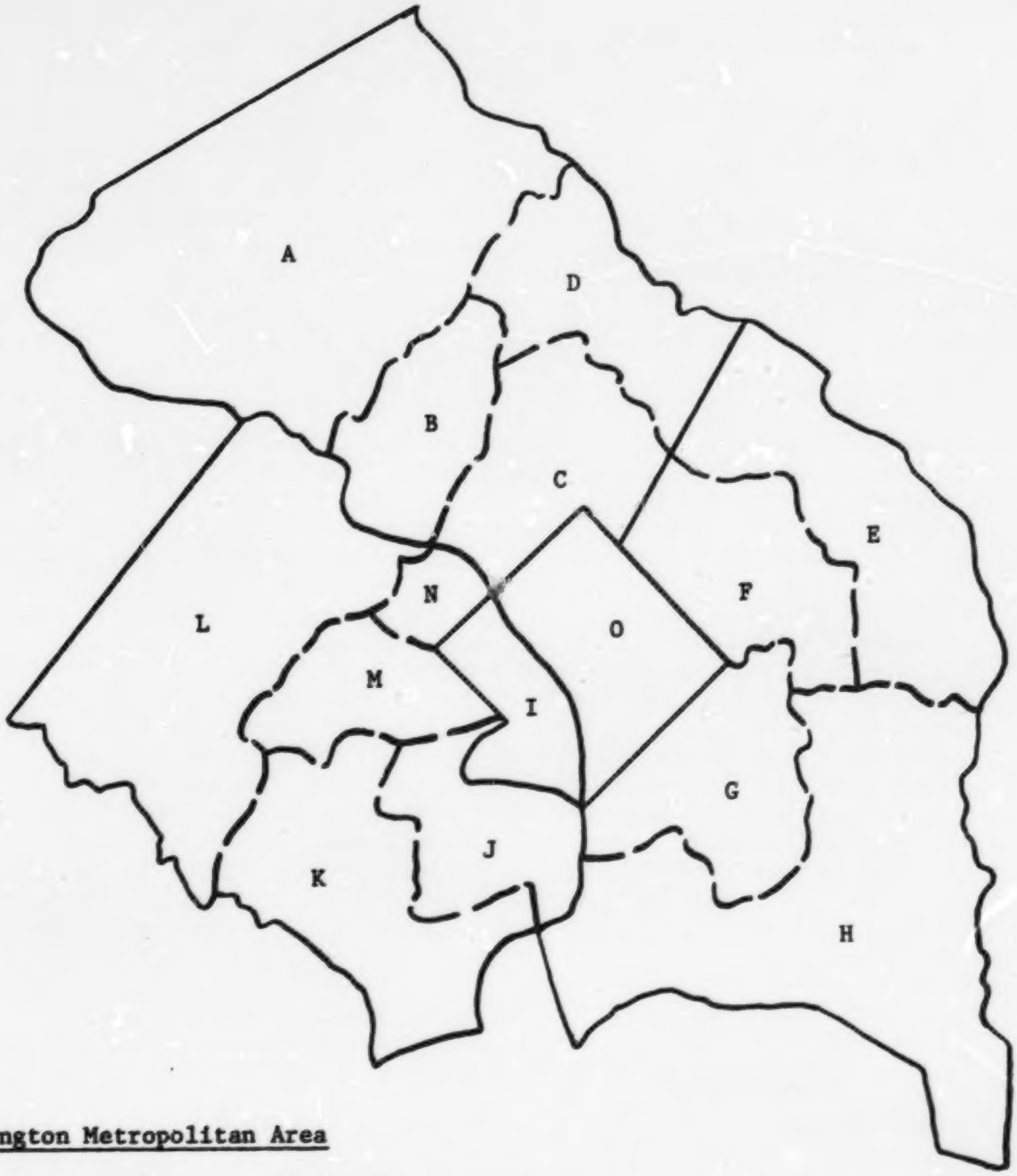
Zone C surrounds the northern tip of the District of Columbia. Included are the areas of Bethesda, Chevy Chase, Four Corners, Silver Spring, and Wheaton. The zone includes the I-70/I-495 (Beltway) interchange. Large increases in population and employment occurred between 1960 and 1968, and new commercial activity has developed along the Beltway section. Federal establishments at Bethesda include the U.S. Navy Hospital and the National Institutes of Health. Land area, 60 square miles.

Zone D is located north of the growth areas of Zones B and C. There has been recent single-family development and a scattering of commercial development along Route 29. Land area, 75 square miles.

b. Prince George's County, Maryland: Zones E,F,G,H -

Zone E encompasses northeast Prince George's County. The National Agriculture Research Center occupies a northern section of the zone. Substantial single-family development occurred from 1960 to 1968, with concentrated development in the towns of Bowie and Belair in the northeast. Land area, including the Agriculture Center, 110 square miles.

Zone F lies in northwest Prince George's County. The zone contains a section of the Beltway, and the interchange with Route 50. The growth



Washington Metropolitan Area

Montgomery County - A,B,C,D
Prince George's County - E,F,G,H
Arlington-Alexandria - I
Fairfax County - J,K,L,M,N
District of Columbia - O

Figure A.9. Dynamic model zones

pattern is similar to Zone C -- rapid development of all types in outer areas near the Beltway. There has been a marked trend toward industrial and commercial land uses along radial highways and the two railroads (B&O and Penn). Land area, 75 square miles.

Zone G borders the southeastern boundary of the District of Columbia. The area has seen rapid residential development. Commercial development has occurred on Route 4 and near the Suitland Parkway (between Andrews Air Force Base and D.C.). Land area, 80 square miles.

Zone H includes the entire southern portion of Prince George's County. Development in the zone has been sparse. Land area, 200 square miles.

c. Arlington County and Alexandria, Virginia: Zone I -

Zone I is the location of National Airport, the Pentagon, and the Arlington National Cemetery. Approaching the zone are several major radial highways including I-95 south, U.S. 66, and the George Washington Parkway. Recently, there have been large commercial and multi-family residential developments. Land area, 40 square miles.

d. Fairfax County, Virginia: Zones J,K,L,M,N -

Zone J is located south of Arlington. It includes the Capital Beltway and a section of I-95. The area has growth rates lagging slightly behind those of other zones which encompass portions of the Beltway. Land area, 50 square miles.

Zone K lies in southern Fairfax County. Located in the zone are Fort Belvoir, the District of Columbia Department of Corrections, and the U.S. Coast Guard Reservation. There has been substantial low-density residential growth, and moderate commercial and industrial development along I-95 and Routes 1 and 123. Land area, 100 square miles.

Zone L includes all of western Fairfax County. It contains sections of the Dulles Access Road and I-66. Located in the zone is the new town of Reston. Residential units and employment more than doubled from 1960 to 1968. Land area, 185 square miles.

Zone M lies west of Arlington County. It includes parts of the Capital Beltway and Route 66. There have been substantial multi-family residential and commercial developments along Routes 66 and 50 and in the City of Fairfax. Land area, 45 square miles.

Zone N lies northeast of Arlington County. It includes parts of the Capital Beltway and the Dulles Access Road. There has been little residential development. Commercial and industrial development has occurred at the intersection of the Dulles Access Road and the Capital Beltway. Land area, 15 square miles.

e. Washington, D.C.: Zone 0 -

While land use has remained relatively unchanged, a large increase in employment has occurred. Residential development has been minimal. Land area, 63 square miles.

3. Simulation of Metropolitan Development -- Results of Washington Model Tests

Simulation results with the Washington model are presented, and land use impacts of infrastructure investments made in the 1960's are discussed. Effects of sewer moratoria were also examined by simulation.

a. Model Accuracy -

In evaluating the "accuracy" of the land use model projections, two criteria were employed: (1) correspondence of projected rates of zonal development (periods of slow/steady/accelerated growth) to observed local growth phases; and (2) comparison of model projections to observed levels in an intermediate year for which consistent data were available.

On the basis of observations by local planners and reference to local publications, simulated growth in most zones followed the correct timing of construction booms and lags. For example, simulation results for Zones B, G, and M are shown in Figures A.10(a), (b), and (c), respectively. Zonal land uses are shown against time. Three variables are plotted for each zone:

- Multi-family residential land (acres)
- Single-family residential land (acres)
- Industrial-commercial land (acres).

Projected values beyond 1974 are based upon a hypothetical program of wastewater investments and simultaneous removal in 1976 of the existing widespread moratoria. No specific land use or sewer controls have been postulated. The projections from 1974 to 1985, therefore, do not necessarily represent a probable course of events, but rather the development potential of zones totally free of development controls and under programs of moderate investment in wastewater facilities.

A more quantitative assessment of model accuracy can be made by comparing projections of the model with available data for the year 1968. Comparisons of simulation projections to observed 1968 values* are presented in Tables A.3 to A.5.

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* The 1960 and 1968 "Actual" Values are derived from data collected by the Council of Governments in its EMPIRIC modeling effort.

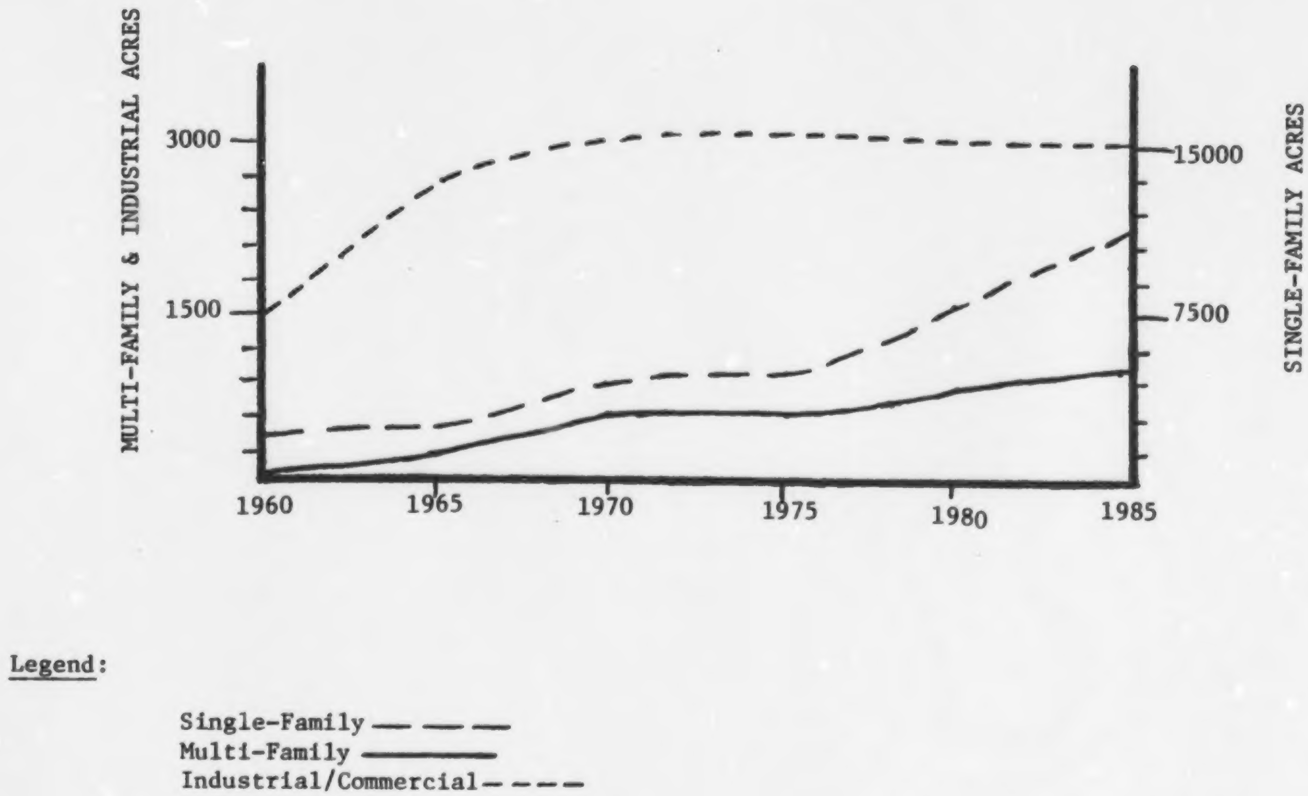

Figure A.10(a). Zonal land use simulation, Zone B

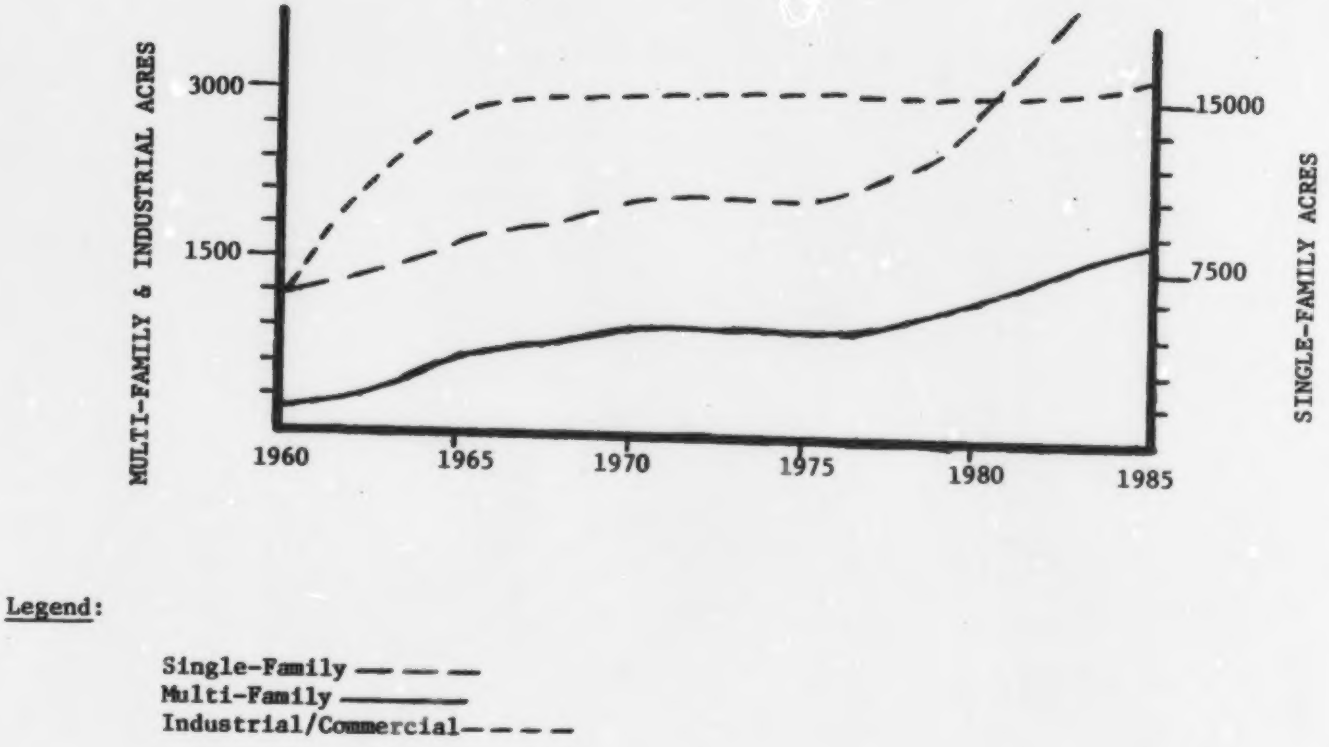

Figure A.10(b). Zonal land use simulation, Zone G

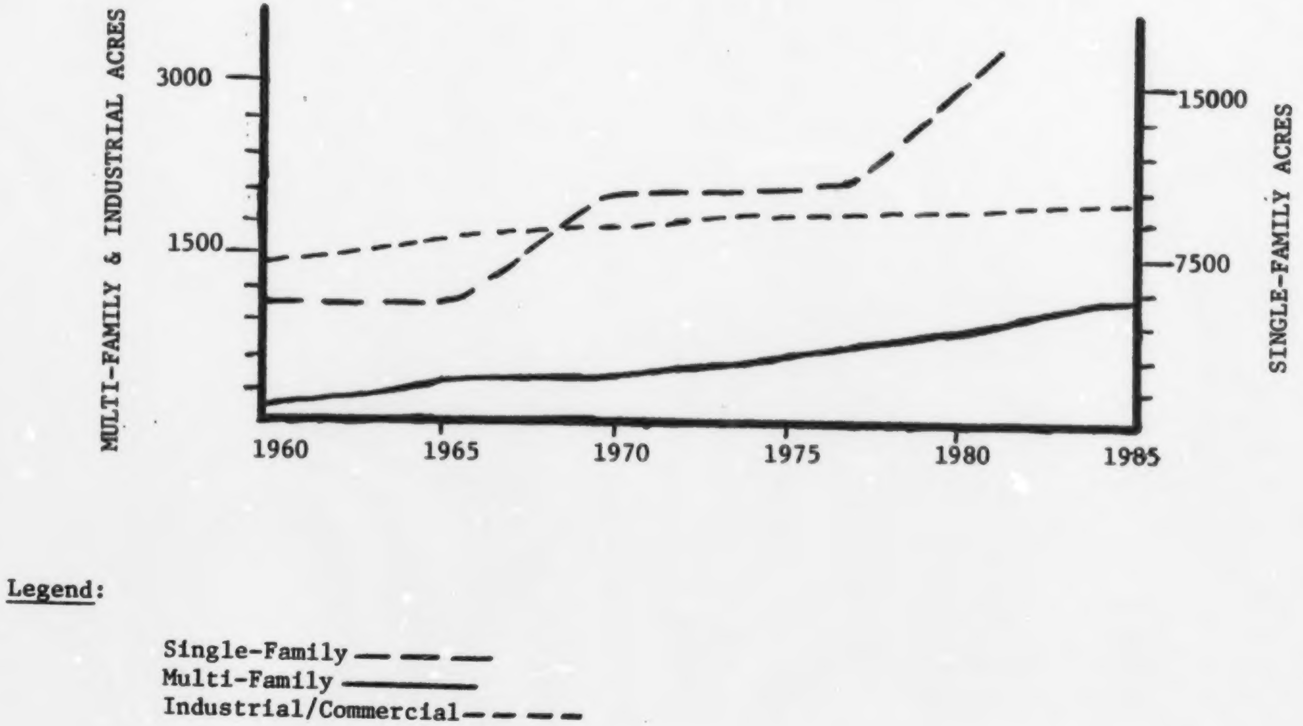

Figure A.10(c). Zonal land use simulation, Zone M

Table A.3. SINGLE-FAMILY RESIDENTIAL UNITS

Zone	1960 Actual	1968 Model	1968 Actual	1968 Model/Actual
A	17,390	19,380	18,660	1.03
B	7,256	13,658	13,610	1.00
C	44,870	56,727	56,220	1.00
D	2,894	5,252	5,663	.93
E	6,255	12,029	17,950	.67
F	37,550	49,824	47,410	1.05
G	20,940	33,012	31,780	1.04
H	3,079	3,882	6,292	.62
I	46,320	50,060	45,800	1.09
J	21,260	28,946	27,280	1.06
K	5,073	6,810	14,320	.48
L	5,047	6,478	9,963	.65
M	23,560	29,800	28,510	1.05
N	6,741	8,098	8,849	.92
O	101,700	99,110	97,550	1.01

Table A.4 MULTI-FAMILY RESIDENTIAL UNITS

Zone	1960 Actual	1968 Model	1968 Actual	1968 Model/Actual
A	11,450	12,625	19,080	.66
B	938	9,295	3,952	2.35
C	4,138	26,487	17,800	1.49
D	118	4,283	182	23.5
E	1,291	7,983	8.195	.97
F	18,300	42,431	41,890	1.01
G	5,723	20,923	27,820	.75
H	136	220	366	.60
I	36,750	44,675	63,320	.71
J	2,148	11,135	9,686	1.15
K	781	2,558	3,268	.78
L	324	1,706	1,530	1.12
M	3,078	11,027	14,850	.74
N	36	3,661	878	4.17
O	150,400	155,460	155,980	.99

Table A.5. EMPLOYMENT

Zone	1960 Actual	1968 Model	1968 Actual	1968 Model/Actual
A	6,130	22,164	11,735	1.89
B	11,298	36,573	24,150	1.51
C	60,840	103,180	106,445	.97
D	3,198	4,824	5,983	.81
E	8,462	17,671	20,090	.88
F	41,234	85,511	70,250	1.22
G	23,043	60,238	42,530	1.42
H	2,438	2,555	4,828	.53
I	124,099	124,960	146,400	.85
J	11,198	41,215	20,820	1.98
K	16,884	20,601	27,540	.75
L	3,300	21,595	9,517	2.27
M	18,940	35,886	37,920	.95
N	4,733	8,373	12,640	.66
O	404,180	427,770	528,400	.81

1. Residential Construction - Projections of single-family housing units are generally accurate, except for Zones E, H, K, and L. In considering general growth patterns, the Zone E discrepancy, though quantitatively large, follows the actual pattern: the model projects a doubling, versus the actual tripling, of units. However, there is in general a notable under-allocation of growth to outlying zones. This indicates that the accessibility function* -- the sensitivity to travel times -- used to evaluate the attractiveness of a zone for single-family development, may have been too restrictive. Alternative shapes for the estimated curves are illustrated in Figure A.11

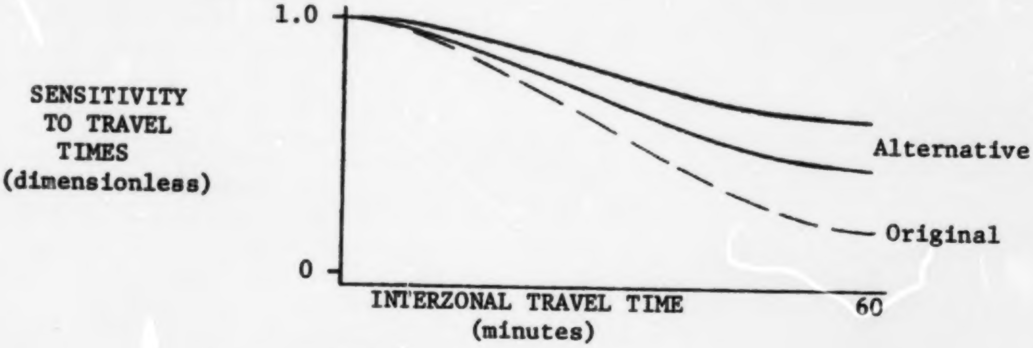

Figure A.11. Sensitivity to travel time

Multi-family housing projections are not as accurate as those for single-family units, though most high-growth areas were successfully simulated. Zones B, C, and D have had large development (D only since 1968), but the model allocated too much growth too soon to these zones. We believe that this was caused by incomplete data on sewer service extensions, a major factor in the attractiveness formulation. Data were obtained for 1960 and 1968 sewer service in the zones. No consistent information on the interim timing of sewer investments was available, so sewer service increases were linearly interpolated over the 1960-1968 period. Examination of the Montgomery County Capital Improvement Program later showed that major investments in Zones B, C, and D were made just prior to 1968, setting the stage for subsequent development. The model simulated development earlier on the assumption that sewer facilities were actually available in the period 1960-1968.

The ratio of projected to actual for Zone G is 0.75 -- the model projecting a tripling of the 6,000 base year units, versus an actual quadrupling.

The model under-allocated development to Zone I. The model formulation of development attractiveness is based upon vacant land and does not include conversion of low density to high density residential use. However, in Zone I (Arlington), substantial conversion of single-family residential land to multi-family use occurred.

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* See page 85.

The large over-allocation by the model to Zone N versus actual was, at least in part, attributable to unusually restrictive zoning in force within parts of the zone.

2. Employment Distribution - The development attractiveness formulation is not generally adequate for the projection of zone employment. Large under-allocations of employment to Zones I and O, Arlington and the District of Columbia, amounted to 120,000 employees. This suggests that the model does not account for growth of employment in central areas with little vacant land. While it is difficult to quantitatively estimate errors arising from central cities, it is a reasonable hypothesis that under-allocation to the two central zones (Arlington and the District of Columbia) resulted in substantial over-allocation to several other zones. A remedial alternative is to specify exogenously employment growth in central zones (without trying to account explicitly for redevelopment and the influence of the Federal government in the central Washington zones) and distribute the rest of development to the rest of the zones where variations in land availability, prices, and public facilities play a larger part in the location of industrial and commercial establishments.

The general performance of the relative attractiveness formulation was encouraging for two reasons: (1) the factors in the formulation were simple and straightforward, designed to represent only major economic forces and major policy interventions; and (2) no attempt was made to calibrate the model with statistically-derived weights or to use Washington-specific factors (e.g., Federal facility location) to insure a good "fit" with observed changes.

In order to provide more succinct and generally recognizable measures of accuracy, 1968 model projections for the fifteen zones were correlated with observed 1968 values. The coefficients of determination (R^2) are shown below.

	R^2
Single-family units	.98
Multi-family units	.98
Employment	.98

The statistically-measured accuracy of the 1968 simulation projections are aided considerably just by initialization of base year (1960) conditions. The results of correlating projected zonal changes with observed changes are presented below.

	R^2
Single-family units	.59
Multi-family units	.50
Employment	.12

Considering the simplicity of the attractiveness formulation relative to statistically-based models fitted to observed historical patterns, the results are good. They indicate that for residential development the formulation has, as hoped, captured the major economic forces behind the location of new construction.

Comparison of 1960-1968 employment projections ($R^2 = .12$) and 1968 employment level projections ($R^2 = .98$) demonstrated that, relative to base year conditions, the distribution of employment changed very little. The factors and weights used in the attractiveness function for employment location were obviously inadequate to describe quantitatively patterns of employment changes within the region.

b. Investment and Policy Tests -

The land use impacts of specific infrastructure investments or investment combinations were identified by simulating development patterns under two conditions: with the investment (or policy), and without it. The differences in development patterns were attributed to the specified investment or policy.

To test this approach, impacts of a series of investments made in the 1960's and recent sewer control policies were simulated. Tests included:

- Interstate 66 - A major radial artery in an east-west direction, connecting with the Capital Beltway. Major travel time changes in 1964 were from Zone L in Fairfax County to all zones directly served by the Beltway and to Arlington-Alexandria and the District.
- The Capital Beltway (Interstate 495) - A 66-mile circumferential highway completed in 1964. The Beltway encircles the District of Columbia, running through inlying portions of Montgomery, Prince George's, and Fairfax Counties.
- Potomac Interceptor - A substantial increase in sewer service for Zone B.
- Moratoria - Restrictions reduced the availability of new sewer service in Prince George's County zones in 1970, and in Montgomery and Fairfax County zones in 1972.

- Postulated Staggered Removal of Moratoria - The same restrictions described above, with one exception: Prince George's County moratoria are postulated to be removed two years ahead of others, in 1974.

Impacts were estimated by using 1975 as the forecast year. The results of the tests are summarized in Table A.6. A striking feature of the Table is the limited geographic extent of impacts from major investments as contrasted to the widespread effects of control measures (moratoria). Moratoria on construction were imposed beginning in 1970 throughout the counties of Prince George's (Maryland), Montgomery (Maryland), and Fairfax (Virginia). Most of these are still in effect and their dates of release are uncertain.

Comparing simulated growth in 1975 with and without moratoria shows that zones in Prince George's County had less growth, and zones in Montgomery and Fairfax more, as a result of imposition of moratoria. This highlights the importance of timing of controls that may be imposed extensively throughout a metropolitan area. Prince George's County was the first subject to moratoria, followed over the next two years by Montgomery and Fairfax. This sequence of events yielded the following impacts in 1975:

- Initial imposition of moratoria within Prince George's County discouraged new development there.
- Developers turned instead to suburban Montgomery and Fairfax Counties.
- Additional development in these two counties exacerbated already large growth rates and heightened sewer problems.
- Subsequently imposed moratoria in Montgomery and Fairfax Counties were not nearly as effective as in Prince George's. Developers had established legal commitments for construction in the form of a backlog of development authorizations.
- The resulting building boom, especially in Montgomery, has only recently begun to slow -- after two years of moratorium controls.

The impacts of moratoria were examined further by extended simulations to 1985 and by making the assumption that moratoria would be lifted in 1976. The simulation of land use in Zone D (Figure A.12(a)) illustrates effects of the moratoria. Residential construction continues through the first years of the moratorium, slowing in 1974, only to resume growth upon the 1976 release of the moratorium. This should be contrasted with the Zone E (in Prince George's County) simulation in Figure A.12(b). Zone E development is halted by the 1970 moratorium,

Table A.6. INVESTMENT AND POLICY IMPACTS

Investment Policy / Zone	I-66		I-495 (Capt'l. Bltwy.)		Zone B Sewer (Potomac Interceptor)		Moratoria		Staged Release Moratoria	
	Residential Land Use	Indust.-Comm. Land Use	Residential Land Use	Indust.-Comm. Land Use	Residential Land Use	Indust.-Comm. Land Use	Residential Land Use	Indust.-Comm. Land Use	Residential Land Use	Indust.-Comm. Land Use
A			+				+			-
B					++				--	-
C			-						--	
D			-				++		--	-
E							-		++	
F							--		++	++
G							--	-	++	++
H										
I										
J							++	++	--	-
K			-				++		-	
L	++						++	+	--	--
M							++		--	-
N							++		--	
O										

Impacts as of 1975: Blank = little or no (0-5%) deviation from base run values; +,- = moderate (5-15%) deviation from base run values; ++,-- = large (greater than 15%) deviation from base run values.

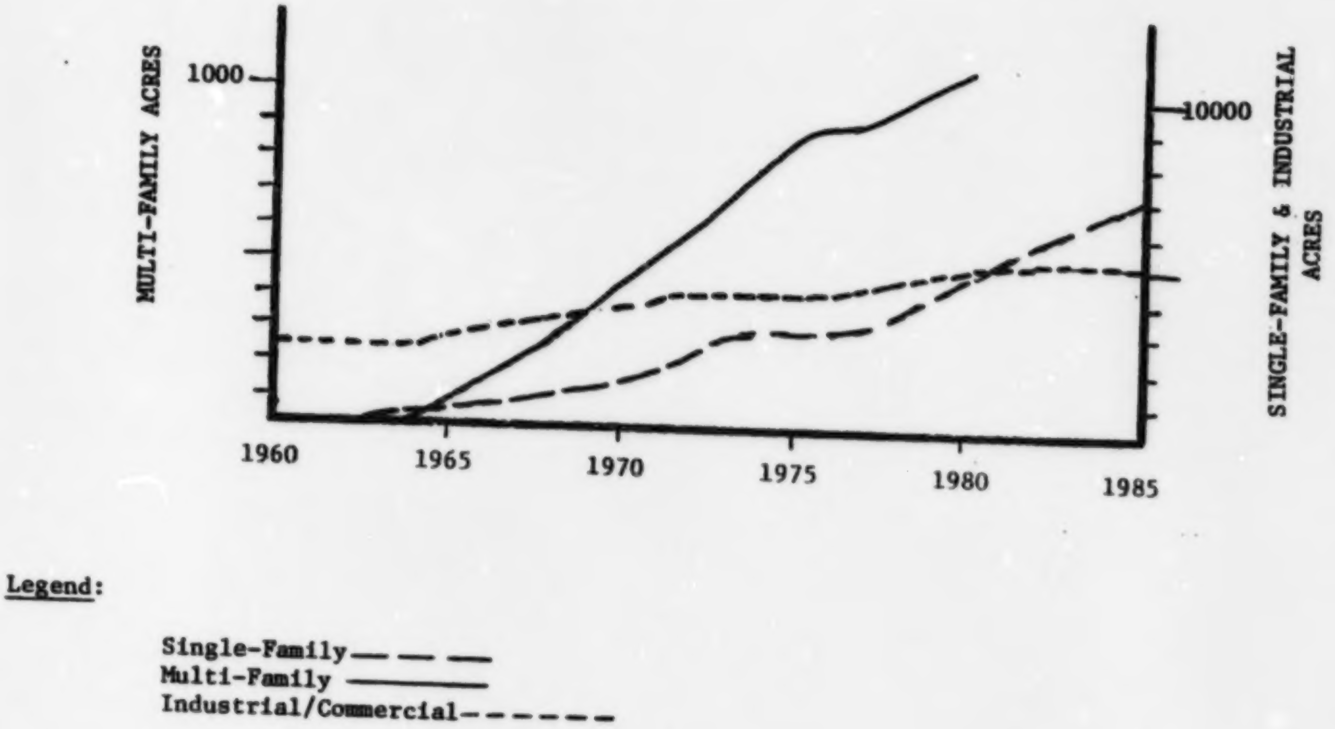

Figure A.12(a). Contrasting zonal land use effects of moratoria (1970-1976), Zone D

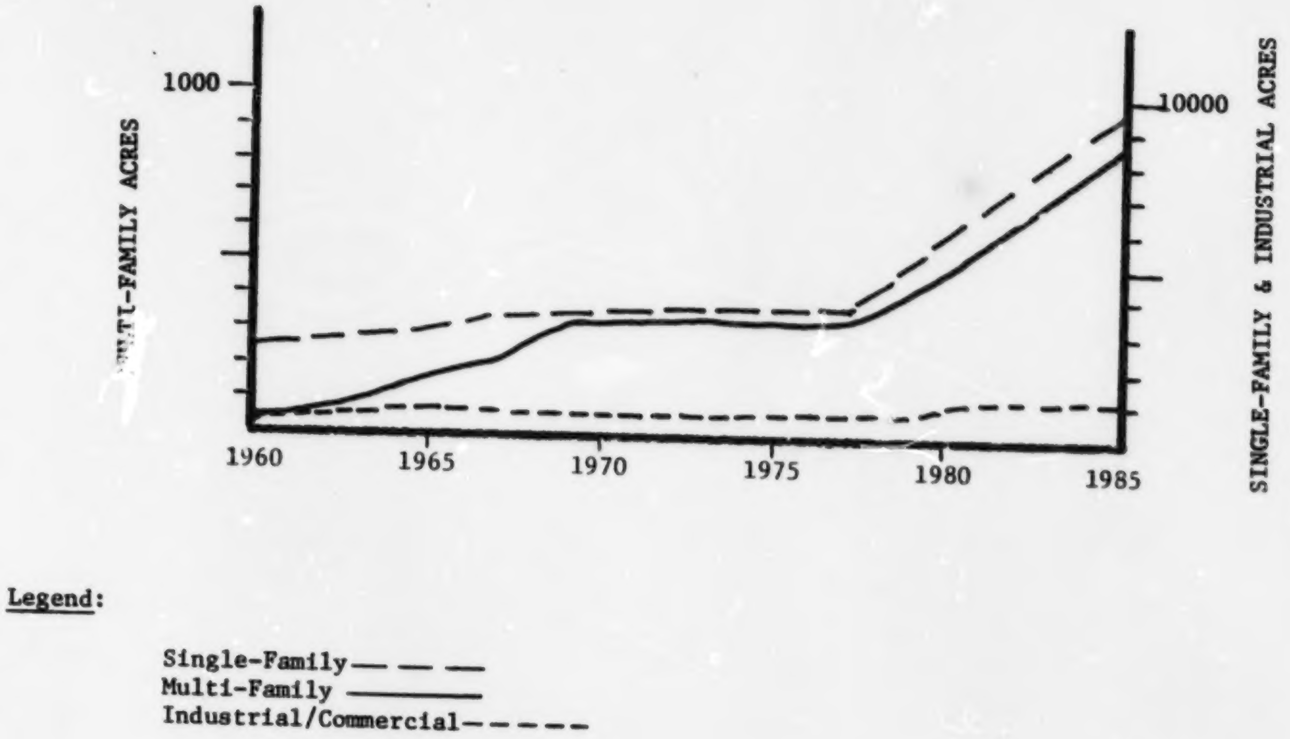

Figure A.12(b). Contrasting zonal land use effects of moratoria (1970-1976), Zone E but it is important to note that growth following the moratorium is at a more rapid rate than before. By 1985, the constraining effect of Zone E moratoria are virtually nullified by more rapid growth occurring without further controls.

Further evidence of the importance of timing is demonstrated in the impacts of removing moratoria in one county (Prince George's in this example) earlier than in other suburban counties. As shown in Table A.6, significant changes are observable for all three counties involved, but in the opposite direction of all impacts of the simultaneously released moratoria.

Figure A.12 presents the results of simulating Zone E land use under three different conditions. Figure A.13(a) illustrates Zone E land use from 1960 to 1985 when moratoria are simultaneously released throughout the metropolitan area. Figure A.13(b) illustrates Zone E land use when the sewer moratorium in Zone E is removed two years earlier (in 1974) than other moratoria. Figure A.13(c) illustrates Zone E land use when an additional investment in Zone E sewer service is made to correspond with a 1974 removal of the Zone E moratorium. The contrasting rates of post-1974 growth in Zone E emphasize the importance of the relative timing of sewer service restrictions and investments.

In sum, the simulation results suggest that relatively isolated but significant impacts result from major highway and sewer investments. Shorter-term, though metropolitan-wide and significant, land use impacts result from the imposition of moratoria in suburban counties.

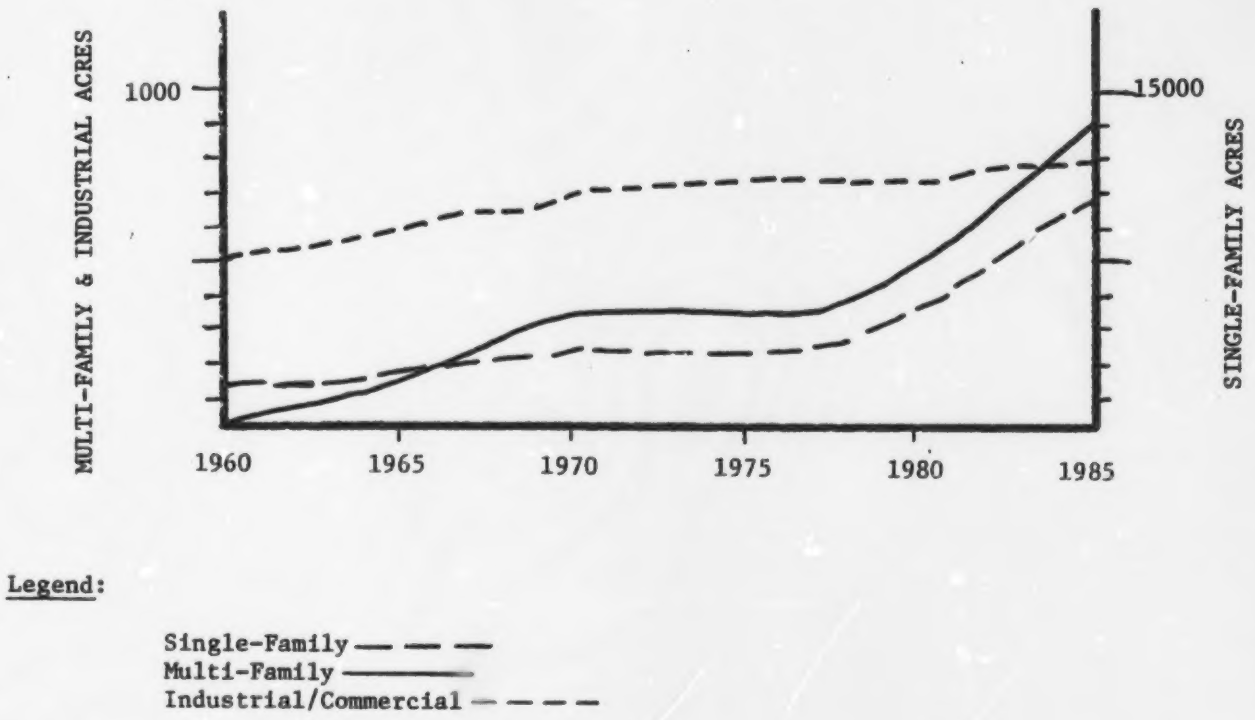

Figure A.13(a). Contrasting effects of different sewer controls on Zone E: simultaneous removal

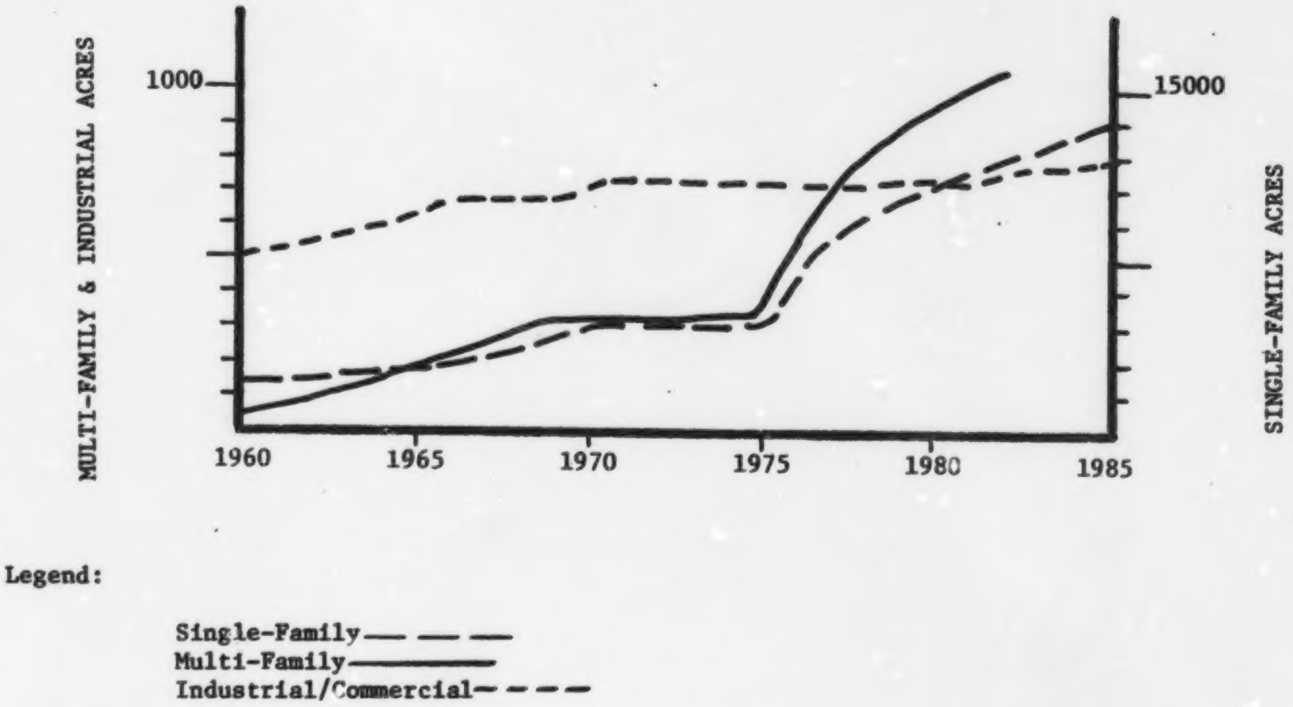

Figure A.13(b). Contrasting effects of different sewer controls on Zone E: selective removal

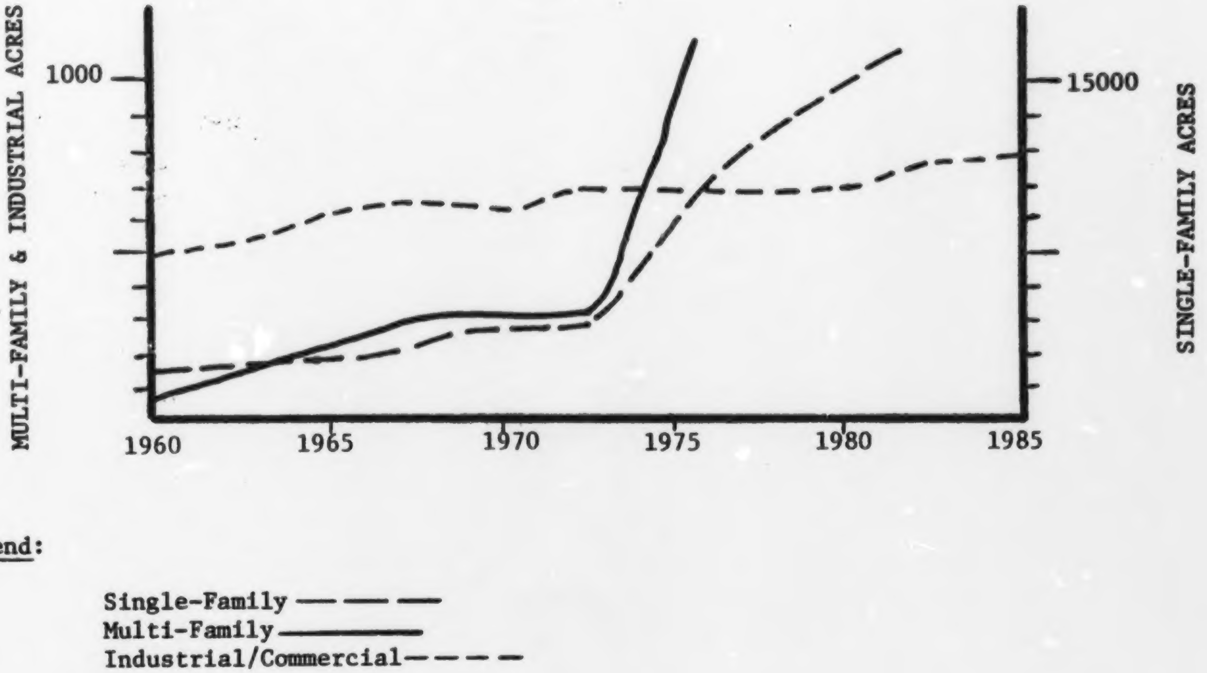

Figure A.13(c). Contrasting effects of different sewer controls on Zone E: early removal and investment

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10. Ibid., p. 28.

11. Ibid., p. 23.

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14. National Capital Region Transportation Planning Board: Information Report No. 29, May 1970, Figure 1.

15. COG, "The State of the Region," Vol. 3, p. 10, Table 2.

16. COG, "The State of the Region," Vol. 1, p. 7.

17. COG, "The State of the Region," Vol. 2, p. 33.

18. COG, "The Changing Region: Policies in Perspective - A Comparison of Plans and Policies with Development Trends," pp. 23-25.

19. COG, "The State of the Region," Vol. 2, p. 31, Table 13.

APPENDIX B

MODEL LISTING

POPULATION SECTOR

```
ACS=6                                                    1, C
     ACS     - AGE CLASSES


POP.K(1)=POP.J(1)+DT*(NBRTH.JK-AGOUT.JK(1)-              2, L
  DTH.JK(1)+INMIG.JK(1))
     POP     - INITIAL POP (MEN)
     NBRTH   - NET BIRTH RATE (MEN/YR)
     AGOUT   - LOSS DUE TO AGING (MEN/YR)
     DTH     - DEATHS BY AGE CLASS (MEN/YR)
     INMIG   - INMIG OF AGE CLASS 1

POP.K(AC2)=POP.J(AC2)+DT*(AGOUT.JK(AC2-1)-               3, L
  AGOUT(AC2)-DTH.JK(AC2)+INMIG.JK(AC2))
POP(AC)=IPOP(AC)                                         3.2, N
IPOP=588166/160864/135059/599715/383233/122390           3.3, T
     POP     - INITIAL POP (MEN)
     AGOUT   - LOSS DUE TO AGING (MEN/YR)
     DTH     - DEATHS BY AGE CLASS (MEN/YR)
     INMIG   - INMIG OF AGE CLASS 1

TTPOP.K=SUMV(POP.K,1,ACS)                                4, A
     TTPOP   - TOTAL POPULATION (MEN)
     POP     - INITIAL POP (MEN)
     ACS     - AGE CLASSES

AGOUT.KL(AC)=POP.K(AC)/LAC(AC)                           5, R
LAC=14/6/5/20/20/1E30                                    5.1, T
     AGOUT   - LOSS DUE TO AGING (MEN/YR)
     POP     - INITIAL POP (MEN)
     LAC     - LENGTH OF AGE CLASSES (YRS)

DTH.KL(AC)=DTHR(AC)*POP.K(AC)                            6, R
DTHR=1.9E-3/.3E-3/.7E-3/1.5E-3/6.6E-3/64.8E-3            6.1, T
     DTH     - DEATHS BY AGE CLASS (MEN/YR)
     DTHR    - TABLE,DEATH RATES (1/YR)
     POP     - INITIAL POP (MEN)

NBRTH.KL=TTBTH.K*(1-DTINF.K)                             7, R
     NBRTH   - NET BIRTH RATE (MEN/YR)
     TTBTH   - TOTAL BIRTHS(MEN/YR)
     DTINF   - DEATH RATE OF INFANTS (1/YR)

TTBTH.K=SUMVV(POP.K,2,ACS$BRTH.K,2,ACS)                  8, A
     TTBTH   - TOTAL BIRTHS(MEN/YR)
     POP     - INITIAL POP (MEN)
     ACS     - AGE CLASSES
     BRTH    - BIRTH RATE BY AGE CLASS(1/YR)
```

```
BRTH.K(AC2)=TBR.K*IBR(AC2)
     BRTH    - BIRTH RATE BY AGE CLASS(1/YR)                    9, A
     TBR     - TREND IN BIRTH RATES (D)
     IBR     - INITIAL BIRTH RATES (1/YR)


TBR.K=TABHL(TTBR,TIME.K,1960,1985,5)
TTBR=1/.8915/.8087/.8306/.8471/.8565                            10, A
IBR=0/30E-3/130E-3/50E-3/.1E-3/0                                10.1, T
     TBR     - TREND IN BIRTH RATES (D)                         10.3, T
     TTBR    - TABLE, BIRTH RATE TREND (D)
     TIME    - EMPLOYMENT SECTOR RELATIVE WAGES
     IBR     - INITIAL BIRTH RATES (1/YR)

DTINF.K=INFMRT*(TDDTIN.K)
     DTINF   - DEATH RATE OF INFANTS (1/YR)                     11, A
     INFMRT  - INFANT MORTALITY (1/YR)
     TDDTIN  - TREND IN INFANT DEATHS (D)

TDDTIN.K=TABHL(TTDIN,TIME.K,1960,1985,25)
TTDIN=1/.08                                                     12, A
     TDDTIN  - TREND IN INFANT DEATHS (D)                       12.2, T
     TTDIN   - TABLE, INFANT DEATH TREND (D)
     TIME    - EMPLOYMENT SECTOR RELATIVE WAGES

INFMRT=22.7E-3
     INFMRT  - INFANT MORTALITY (1/YR)                          12.3, C

INMIG.KL(1)=SUMVV(CHPP.K,2,ACS,INMIG.JK,2,ACS)
     INMIG   - INMIG OF AGE CLASS 1                             13, R
     CHPP    - CHLDRN PER PARENT (MEN)
     ACS     - AGE CLASSES

CHPP.K(AC2)=ICHPP(AC2)*(POP.K(1)/INCHL.K)
     CHPP    - CHLDRN PER PARENT (MEN)                          14, A
     ICHPP   - INDICATED CHL PER PARENT (D)
     POP     - INITIAL POP (MEN)
     INCHL   - INDICATED CHL TOTAL (D)

INCHL.K=SUMVV(ICHPP,2,ACS,POP.K,2,ACS)
ICHPP=0/.09/.473/.903/.0875/0                                   15, A
     INCHL   - INDICATED CHL TOTAL (D)                          15.1, T
     ICHPP   - INDICATED CHL PER PARENT (D)
     ACS     - AGE CLASSES
     POP     - INITIAL POP (MEN)
```

```
INMIG.KL(AC2)=POP.K(AC2)*(EFA(AC2)+EFB(AC2)*
  UEFEM.K)                                              16, R
EFA=0/-.0091/.0037/.0017/-.0061/-.0062
EFB=0/-.499/-1.31/-.308/-.134/-.08                      16.1, T
    INMIG  - INMIG OF AGE CLASS 1                       16.3, T
    POP    - INITIAL POP (MEN)
    EFA    - MIG FACTOR A (D)
    EFB    - MIG FACTOR B (D)
    UEFEM  - UNEMPLOYMENT EFFECT ON MIG (D)

                    EMPLOYMENT SECTOR

WKPP.K=TTPOP.K-POP.K(1)
    WKPP   - WORKING POPULATION (MEN)                   17, A
    TTPOP  - TOTAL POPULATION (MEN)
    POP    - INITIAL POP (MEN)


REWKPP.K=TTEPWK.K/WKPP.K
    REWKPP - RATIO OF EMPLOYED TO WORKERS               18, A
    TTEPWK - TOTAL EMPLOYED WORKERS (MEN)
    WKPP   - WORKING POPULATION (MEN)

TTEPWK.K=EXINWK.K+BSSVWK.K+HHSVWK.K+GEMWK.K
    TTEPWK - TOTAL EMPLOYED WORKERS (MEN)               19, A
    EXINWK - EXP IND WORKERS (MEN)
    BSSVWK - INIT BS SERV WKRS (MEN)
    HHSVWK - INITIAL HSHOLD SERVG WKRS (MEN)
    GEMWK  - GOVT, EDUC, MILIT WORKERS (MEN)

AGLFPR.K=TTLBFR.K/TTPOP.K
    AGLFPR - AGGREGATE LABOR FORCE PARTICIPATION (D)    20, A
             TOTAL LABOR FORCE FORECAST
    TTLBFR - TOTAL LABOR FORCE (MEN)
    TTPOP  - TOTAL POPULATION (MEN)

TTLBFR.K=SUMVV(LBFRPR.K,2,ACS,POP.K,2,ACS)
    TTLBFR - TOTAL LABOR FORCE (MEN)                    21, A
    ACS    - AGE CLASSES
    POP    - INITIAL POP (MEN)

LBFRPR.K(AC2)=INLBFR(AC2)+(LFA(AC2)*(REWKPP.K-
  IREWKP))                                              22, A
IPEWKP=REWKPP
INLBFR=0/.306/.709/.714/.710/.229                       22.1, N
LFA=0/.46/1.09/.707/.86/.65                             22.2, T
    INLBFR - INIT LB FR PARTICIPATION (D)               22.3, T
    LFA    - LABOR FACTOR A (D)UNEMPLOYMENT FORECASTS
    REWKPP - RATIO OF EMPLOYED TO WORKERS
    IREWKP - LABOR FORCE PARTICIPATION (D)
```

```
UNEPWK.K=TTLBFR.K-TTEPWK.K                                    23, A
     UNEPWK - UNEMPLOYED WORKERS (MEN)
     TTLBFR - TOTAL LABOR FORCE (MEN)
     TTEPWK - TOTAL EMPLOYED WORKERS (MEN)

LCUNEP.K=UNEPWK.K/TTLBFR.K                                    24, A
     LCUNEP - LOCAL UNEMPLOYMENT (D)
     UNEPWK - UNEMPLOYED WORKERS (MEN)
     TTLBFR - TOTAL LABOR FORCE (MEN)

SLUERT.K=SMOOTH(LCUNEP.K,1)                                   25, A
     SLUERT - SMOOTHED LOCAL UNEMPLOYMENT (D)
     LCUNEP - LOCAL UNEMPLOYMENT (D)

UEFEM.K=MIN(DUER.K,DDUER.K)                                   26, A
     UEFEM  - UNEMPLOYMENT EFFECT ON MIG (D)
     DUER   - DIFFERENCE IN UNEMP RATES (D)
     DDUER  - DELAYED DIFF IN UNEMP RATES (D)

DDUER.K=SMOOTH(DUER.K,2)                                      27, A
     DDUER  - DELAYED DIFF IN UNEMP RATES (D)
     DUER   - DIFFERENCE IN UNEMP RATES (D)


DUER.K=LCUNEP.K-NATUER                                        28, A
     DUER   - DIFFERENCE IN UNEMP RATES (D)
     LCUNEP - LOCAL UNEMPLOYMENT (D)
     NATUER - NATIONAL UNEMPLOYMENT (D)

NATUER=.05                                                    28.1, C
TIME=1960                                                     28.2, N
     NATUER - NATIONAL UNEMPLOYMENT (D)
     TIME   - EMPLOYMENT SECTOR RELATIVE WAGES

RGRLWG.K=RGRLWG.J+DT*(1/10)(TGRLWG.J-RGRLWG.J)                29, L
RGRLWG=INRRWG                                                 29.2, N
INRRWG=1.1                                                    29.3, C
     RGRLWG - REGIONAL RELATIVE WAGE (D)
     TGRLWG - TARGET RELATIVE WAGE (D)

TGRLWG.K=.4+.3*(AGAVWG.K)                                     30, A
     TGRLWG - TARGET RELATIVE WAGE (D)
     AGAVWG - AGGREGATE AV. WAGES  ($/MAN)
```

```
AGAVWG.K=(EXINWG.K+BSSVWG.K+HHSVWG.K+GEMWG.K)/          31, A
  (TTEPWK.K)
    AGAVWG - AGGREGATE AV. WAGES  ($/MAN)
    EXINWG - EXP IND WAGES ($)
    BSSVWG - BUS SERV IND WAGES ($)
    HHSVWG - HSHD SERV WAGES ($)
    GEMWG  - GOV,ED,MIL WAGES ($)
    TTEPWK - TOTAL EMPLOYED WORKERS (MEN)

EXINWG.K=(RGRLWG.K)(INEXWG)(EXINWK.K)                   32, A
INEXWG=2.49                                             32.1, C
    EXINWG - EXP IND WAGES ($)
    RGRLWG - REGIONAL RELATIVE WAGE (D)
    INEXWG - INITIAL EXP WAGES ($/MAN)
    EXINWK - EXP IND WORKERS (MEN)

BSSVWG.K=(RGRLWG.K)(INBSWG)(BSSVWK.K)                   33, A
INBSWG=2.55                                             33.1, C
    BSSVWG - BUS SERV IND WAGES ($)
    RGRLWG - REGIONAL RELATIVE WAGE (D)
    INBSWG - INITIAL BUS SERV WAGES ($/MAN)
    BSSVWK - INIT BS SERV WKRS (MEN)

HHSVWG.K=(RRLMDWG.K)(INHHWG)(HHSVWK.K)                  34, A
INHHWG=1.95                                             34.1, C
    HHSVWG - HSHD SERV WAGES ($)
    INHHWG - INIT HSHD SERV WAGES ($/MAN)
    HHSVWK - INITIAL HSHOLD SERVG WKRS (MEN)

GEMWG.K=(RGRLWG.K)(INGEMW)(GEMWK.K)                     35, A
INGEMW=2.51                                             35.1, C
    GEMWG  - GOV,ED,MIL WAGES ($)
    RGRLWG - REGIONAL RELATIVE WAGE (D)
    INGEMW - INIT GOV,ED,MIL WAGES ($/MAN)/
    GEMWK  - GOVT, EDUC, MILIT WORKERS (MEN)


RRLMDW.K=RRLMDW.J+DT*(1/10)(TRLMDW.J-RRLMDW.J)          36, L
RRLMDW=IRLMDW                                           36.2, N
IRLMDW=1.08                                             36.3, C
    RRLMDW - DEPENDENT WAGE (D)
    TRLMDW - TARGET RELATIVE LABOR MARKET DEPENDENT WAGE
               (D)EXPORT INDUSTRY EMPLOYMENT    .
    IRLMDW - INITIAL RELATIVE LMD WAGE (D)

TRLMDW.K=.525+(.3)(AGAVWG.K)+(-2.5)(SLUERT.K)           37, A
    TRLMDW - TARGET RELATIVE LABOR MARKET DEPENDENT WAGE
               (D)EXPORT INDUSTRY EMPLOYMENT
    AGAVWG - AGGREGATE AV. WAGES  ($/MAN)
    SLUERT - SMOOTHED LOCAL UNEMPLOYMENT (D)
```

```
EXINWK.K=EXINWK.J+(DT)(EPCH.JK)                                38, L
EXINWK=INEXWK                                                  38.1, N
INEXWK=116234                                                  38.2, C
     EXINWK - EXP IND WORKERS (MEN)
     EPCH   - EMPLOYMENT CHANGE (MEN/YR)
     INEXWK - INITIAL EXP WORKERS (MEN)

EPCH.K=(PEPCH.K)(EXINWK.K)                                     39, A
     EPCH   - EMPLOYMENT CHANGE (MEN/YR)
     PEPCH  - FRACTION EMPLYMNT CHG (1/YR)
     EXINWK - EXP IND WORKERS (MEN)

PEPCH.K=GRLBDM-(CSLES)(RLCST.K)                                40, A
     PEPCH  - FRACTION EMPLYMNT CHG (1/YR)
     GRLBDM - GRWTH RT IN LB DEMAND (MEN/YR)
     CSLES  - COST ELASTICITY(D)
     RLCST  - RELATIVE COST (D)

RLCST.K=TTCSIX.K-1                                             41, A
     RLCST  - RELATIVE COST (D)
     TTCSIX - TOTAL COST INDEX (D)

TTCSIX.K=CNCSFC+MKACFC+MTACFC+(LBCSWT)(RGRLWG.K)               42, A
GRLBDM=.01                                                     42.2, C
CSLES=.4                                                       42.3, C
CNCSFC=.7519                                                   42.4, C
MKACFC=.027                                                    42.5, C
MTACFC=.018                                                    42.6, C
LBCSWT=.22                                                     42.7, C
     TTCSIX - TOTAL COST INDEX (D)
     CNCSFC - WEIGHTED REG CNST CST FCTR (D)
     MKACFC - WGHTD REG MKT ACCESS FCTR (D)
     MTACFC - WGHTD REG MTL ACCESS FCTR (D)
     LBCSWT - WEIGHT FOR REG LB CST FCTR (D)
     RGRLWG - REGIONAL RELATIVE WAGE (D)
     GRLBDM - GRWTH RT IN LB DEMAND (MEN/YR)
     CSLES  - COST ELASTICITY(D)

GEMWK.K=TABHL(TGEM,TIME.K,1960,1990,10)                        43, A
TGEM=316836/463430/620000/770000                               43.2, T
     GEMWK  - GOVT, EDUC, MILIT WORKERS (MEN)
     TGEM   - TABLE, GOV,ED,MIL EMPL (MEN)
     TIME   - EMPLOYMENT SECTOR RELATIVE WAGES
```

```
        BUSINESS-SERVING INDUSTRY EMPLOYMENT

  BSSVWK.K=BSSVWK.J+DT*(BSIGR.J)                                  44, L
  BSSVWK=INBSWK                                                   44.1, N
  INBSWK=115515                                                   44.2, C
       BSSVWK - INIT BS SERV WKRS (MEN)
       BSIGR  - BUS SERVG IND GRWTH RT (MEN/YR)

  BSIGR.K=LBAVML.K*DBSIGR.K                                       45, A
       BSIGR  - BUS SERVG IND GRWTH RT (MEN/YR)
       LBAVML - LABOR AVAILABILITY MULTIP (D)
       DBSIGR - DESD BS SER GRWTH RT (MEN/YR)

  DBSIGR.K=TABHL(TDBSG,DABSWK.K,-1E5,1E5,1E5)                     46, A
  TDBSG=-1E5/0/3E4 (MEN/YR)                                       46.2, T
       DBSIGR - DESD BS SER GRWTH RT (MEN/YR)
       TDBSG  - TABLE,DESD BS SERV GRWTH RT (MEN/YR)
       DABSWK - DESRD ADD BUS SERVG WKRS (MEN)

  DABSWK.K=DBSWK.K-BSSVWK.K                                       47, A
       DABSWK - DESRD ADD BUS SERVG WKRS (MEN)
       DBSWK  - DESRD BUS SERVG WKRS (MEN)
       BSSVWK - INIT BS SERV WKRS (MEN)

  DBSWK.K=WBSS*WKISNV.K                                           48, A
  WBSS=.165                                                       48.1, C
       DBSWK  - DESRD BUS SERVG WKRS (MEN)
       WBSS   - DESD BS SERV WKRS PER WKR (D)
       WKISNV - WKRS IN INDUSTRIES SERVED (MEN) HOUSEHOLD-
                   SERVING INDUSTRY EMPLOYMENT

  WKISNV.K=TTEPWK.K-BSSVWK.K                                      49, A
       WKISNV - WKRS IN INDUSTRIES SERVED (MEN) HOUSEHOLD-
                   SERVING INDUSTRY EMPLOYMENT
       TTEPWK - TOTAL EMPLOYED WORKERS (MEN)
       BSSVWK - INIT BS SERV WKRS (MEN)


  HHSVWK.K=HHSVWK.J+DT*(HSIGR.J)                                  50, L
  HHSVWK=INHSWK                                                   50.1, N
  INHSWK=301646                                                   50.2, C
       HHSVWK - INITIAL HSHOLD SERVG WKRS (MEN)
       HSIGR  - HSHOLD SERVG IND GRWTH RT (MEN/YR)

  HSIGR.K=(LBAVML.K)(DHSIG.K)                                     51, A
       HSIGR  - HSHOLD SERVG IND GRWTH RT (MEN/YR)
       LBAVML - LABOR AVAILABILITY MULTIP (D)
       DHSIG  - DESRD HSHOLD SERV IND GRWTH RT (MEN/YR)
```

```
DHSIG.K=TABHL(TDHSG,DAHSW.K,-1E5,3E5,1E5)
TDHSG=-1E5/0/3E4/6E4/9E4 (MFN/YR)                            52, A
    DHSIG  - DESRD HSHOLD SERV IND GRWTH RT (MEN/YR)          52.3, T
    TDHSG  - TABLE, DESD HSHD SER GRWTH RT
    DAHSW  - DESRD ADD HSHOLD SERVG WKRS (MEN)


DAHSW.K=DHSWK.K-HHSVWK.K
    DAHSW  - DESRD ADD HSHOLD SERVG WKRS (MEN)                53, A
    DHSWK  - DESRB HSHLD SERVG WKRS
    HHSVWK - INITIAL HSHOLD SERVG WKRS (MEN)

DHSWK.K=WHSS*TTPOP.K*TRWHSS.K
WHSS=.19562 (D)                                              54, A
    DHSWK  - DESRB HSHLD SERVG WKRS                          54.1, C
    WHSS   - DESD HSHD SERV WKR PER CAPITA
    TTPOP  - TOTAL POPULATION (MEN)

TRWHSS.K=TABHL(TTRHW,TIME.K,1960,1985,25)
TTRHW=1/1.08 (D)                                             55, A
    TTRHW  - TABLE, TREND IN HSHD SERV WKRS TREND IN         55.1, T
                 HSHLD SERVING WKRS (D)
    TIME   - EMPLOYMENT SECTOR RELATIVE WAGES


LBAVML.K=TABHL(TLAM,LCUNEP.K,0,.1,.05)
TLAM=0/.8/1                                                  56, A
    LBAVML - LABOR AVAILABILITY MULTIP (D)                   56.2, T
    TLAM   - TABLE, LB AVAIL MULTIP (D)
    LCUNEP - LOCAL UNEMPLOYMENT (D)

    INDUSTRIAL SECTOR

ZNS=15
DENS=3                                                       56.6, C
SEW=2                                                        56.7, C
                                                             56.8, C


INDLND.K(Z)=INDLND.J(Z)+DT*CMINLN.JK(Z)
INDLND(Z)=IND(Z)*IINCN(Z)                                    61, L
IND=24590/12680/42380/3508/9196/41470/25650/2546/            61.2, N
  103400/12520/18190/3980/20400/5171/439000                  61.3, T
IINCN=.098/.131/.047/.723/.053/.046/.058/.121/.016/          61.6, T
  .133/.048/.323/.058/.267/.014
    INDLND - INITIAL IND LAND (ACRES)
    CMINLN - COMPLETED IND CONST (ACRES/YR)
    IND    - ZOAL INITIAL IND (MEN)
    IINCN  - INITIAL ZONAL IND CONST FACTORS (ACRES/MAN)
```

```
CMINLN.KL(Z)=DELAYP(INCON.K(Z),CINDEL,ICIPZ.K(Z))    62, R
CINDEL=1.5                                           62.2, C
    CMINLN - COMPLETED IND CONST (ACRES/YR)
    INCON  - IND CONST IN PROCESS (ACRES)
    CINDEL - CONST DELAY FOR IND (YRS)


INCON.K(Z)=MAX(0,(ZINDM.K(Z)-(ICIPZ.K(Z))(DPZIC)))* 63, A
  ZAILML.K(Z)
INCON(Z)=IICIPZ(Z)                                   63.2, N
IICIPZ=218/162/280/89/133/54/117/20/68/105/87/[illegible]96/  63.3, T
  108/0/29
DPZIC=1.0                                            63.5, C
    INCON  - IND CONST IN PROCESS (ACRES)
    ZINDM  - ZONAL IND LAND DEMAND (ACRES)
    DPZIC  - DEVEL'S PERCEPT OF IND CONST IN PROCESS (D)
    ZAILML - AVAIL IND LAND MULTIP (D)RESIDENTIAL SECTOR
    IICIPZ - INITIAL CONST ON IND LAND (ACRES)

ZINDM.K(Z)=(ATIND.K(Z)/TTATIN.K)*INLDDM.K*          64, A
  INCNF.K(Z)
    ZINDM  - ZONAL IND LAND DEMAND (ACRES)
    ATIND  - ATTRACTIVENESS FOR INDUSTRY (D)
    TTATIN - TOTAL ATTRACTIVENESS FOR IND (D)
    INLDDM - REG'L IND LAND DEMMAND (MEN)
    INCNF  - INITIAL IND DENS (ACRES/MAN)

INCNF.K(Z)=CNFM(Z)*IICNF.K(Z)                        65, A
INCNF(Z)=IINCN(Z)                                    65.1, N
CNFM=.44/.70/.80/3.70/.21/.567/.47/.42/.9/.65/.22/  65.2, T
  1.6/.71/1.87/1.2
    INCNF  - INITIAL IND DENS (ACRES/MAN)
    CNFM   - IND DENS ADJ FACTOR (D)
    IICNF  - INDICATED IND DENS (ACRES/MAN)
    IINCN  - INITIAL ZONAL IND CONST FACTORS (ACRES/MAN)

IICNF.K(Z)=TABHL(INDNT,UNDEVR.K(Z),0,1.0,.2)        66, A
INDNT=.012/.02/.05/.08/.11/.3                        66.2, T
    IICNF  - INDICATED IND DENS (ACRES/MAN)
    INDNT  - TABLE, IND DENS (ACRES/MAN)
    UNDEVR - UNDEVELOPED RATIO (D)

UNDEVR.K(Z)=UNDEV.K(Z)/ZDL.K(Z)                      67, A
    UNDEVR - UNDEVELOPED RATIO (D)
    UNDEV  - UNDEVELOPED LAND (ACRES)
    ZDL    - ZONAL DEVELOPABLE LAND (ACRES)
```

```
UNDEV.K(Z)=ZDL.K(Z)-(INDLND.K(Z)+TRL.K(Z))(1+                 68, A
  ODEV(Z))
    UNDEV  - UNDEVELOPED LAND (ACRES)
    ZDL    - ZONAL DEVELOPABLE LAND (ACRES)
    INDLND - INITIAL IND LAND (ACRES)
    TRL    - TOTAL ZONAL RESID LAND (ACRES)
    ODEV   - TABLE, OTHER DEVEL FRACTION (D

INLDDM.K=TTEPWK.K*INCWML.K                                     69, A
    INLDDM - REG'L IND LAND DEMMAND (MEN)
    TTEPWK - TOTAL EMPLOYED WORKERS (MEN)
    INCWML - IND CROWDING MULTIPLIER (D)

INCWML.K=TABHL(TICM,INCRW.K,.80,1.20,.05)                      70, A
    INCWML - IND CROWDING MULTIPLIER (D)
    TICM   - TABLE, IND CROWDING MULTIP (D)
    INCRW  - IND CROWDING (D)


INCRW.K=TTEPWK.K/TEPWKS.K                                      71, A
TICM=1E-15/1E-15/1E-15/.01/.02/.05/.08/.09/.1                  71.1, T
    INCRW  - IND CROWDING (D)
    TTEPWK - TOTAL EMPLOYED WORKERS (MEN)
    TEPWKS - TOTAL EMPL WKRS SERVED (MEN)
    TICM   - TABLE, IND CROWDING MULTIP (D)

TEPWKS.K=SUMV(EPWKS.K(*),1,ZNS)                                72, A
    TEPWKS - TOTAL EMPL WKRS SERVED (MEN)
    EPWKS  - ZONAL EMPL WKRS SERVED (MEN)

EPWKS.K(Z)=INDLND.K(Z)/INCNF.K(Z)                              73, A
    EPWKS  - ZONAL EMPL WKRS SERVED (MEN)
    INDLND - INITIAL IND LAND (ACRES)
    INCNF  - INITIAL IND DENS (ACRES/MAN)

ZEPWK.K(Z)=EPWKS.K(Z)*INCRW.K                                  74, A
    ZEPWK  - ZONAL EMPLOYMENT (MEN)
    EPWKS  - ZONAL EMPL WKRS SERVED (MEN)
    INCRW  - IND CROWDING (D)

ZAILML.K(Z)=MIN(1,AVLNI.K(Z)/ZINDM.K(Z))                       75, A
    ZAILML - AVAIL IND LAND MULTIP (D)RESIDENTIAL SECTOR
    AVLNI  - ACTUAL AVAIL IND LAND (ACRES)
    ZINDM  - ZONAL IND LAND DEMAND (ACRES)
```

```
HSU.K(D,Z)=HSU.J(D,Z)+DT*(CMHSU.JK(D,Z)-CLHSU.JK(D, 76, L
  Z))
HSU(D,Z)=IHU(D,Z)                                     76.2, N
IHU(*,1)=11450/14390/3000                             76.3, T
IHU(*,2)=938/6256/1000                                76.4, T
IHU(*,3)=4138/40370/4500                              76.5, T
IHU(*,4)=118/2394/500                                 76.6, T
IHU(*,5)=1291/5600/655                                76.7, T
IHU(*,6)=18300/33550/4000                             76.8, T
IHU(*,7)=5723/18940/2000                              76.9, T
IHU(*,8)=136/0/3079                                   77.1, T
IHU(*,9)=36750/46000/320                              77.2, T
IHU(*,10)=2148/20060/1200                             77.3, T
IHU(*,11)=781/4573/500                                77.4, T
IHU(*,12)=324/4547/500                                77.5, T
IHU(*,13)=3078/21560/2000                             77.6, T
IHU(*,14)=36/6641/100                                 77.7, T
IHU(*,15)=150400/101300/400                           77.8, T
      HSU    - INITIAL HOUSING UNITS (UNITS)
      CMHSU  - COMPLETED HOUSING (UNITS/YR)
      CLHSU  - CLEARED LOW DENS NON-SEWERED
      IHU    - INITIAL HOUSING UNITS (UNITS)

TTHSU.K(D)=SUMV(HSU.K(D,*),1,ZNS)                     78, A
      TTHSU  - TOTAL HOUSING UNITS (UNITS)
      HSU    - INITIAL HOUSING UNITS (UNITS)


RL.K(D,Z)=HSU.K(D,Z)*PPHSU.K(D)*RCF(D,Z)              79, A
      RL     - RESIDENTIAL LAND (ACRES)
      HSU    - INITIAL HOUSING UNITS (UNITS)
      PPHSU  - MEN PER UNIT (MEN/UNIT)
      RCF    - RESID CONST FACTORS (ACRES/MAN)
```

```
PPHSU.K(D)=TABHL(TPPHU(*,D),TIME.K,1960,1968,8)
TPPHU(*,1)=2.60/2.76                                            80, A
TPPHU(*,2)=3.82/3.52                                            80.2, T
TPPHU(*,3)=3.82/3.52                                            80.3, T
RCF(*,1)=.02/.08/.08                                            80.4, T
RCF(*,2)=.015/.08/.08                                           80.6, T
RCF(*,3)=.015/.08/.08                                           80.7, T
RCF(*,4)=.02/.08/.08                                            80.8, T
RCF(*,5)=.015/.08/.08                                           80.9, T
RCF(*,6)=.015/.08/.08                                           81.1, T
RCF(*,7)=.015/.08/.08                                           81.2, T
RCF(*,8)=.02/.08/.08                                            81.3, T
RCF(*,9)=.015/.08/.08                                           81.4, T
RCF(*,10)=.015/.08/.08                                          81.5, T
RCF(*,11)=.015/.08/.08                                          81.6, T
RCF(*,12)=.015/.06/.08                                          81.7, T
RCF(*,13)=.015/.08/.08                                          81.8, T
RCF(*,14)=.02/.08/.08                                           81.9, T
RCF(*,15)=.0085/.043/.043                                       82.1, T
    PPHSU  - MEN PER UNIT (MEN/UNIT)                            82.2, T
    TPPHU  - TABLE, MEN PER UNIT (MEN/UNIT)
    TIME   - EMPLOYMENT SECTOR RELATIVE WAGES
    RCF    - RESID CONST FACTORS (ACRES/MAN)

CMHSU.KL(D,Z)=DELAY3(RC.K(D,Z),RCDEL(D))
RCDEL=1.5/1.5/1.5                                               83, R
    CMHSU  - COMPLETED HOUSING (UNITS/YR)                       83.2, T
    RC     - RESID CONST (UNITS)
    RCDEL  - RESID CONST DELAY (YRS)

RC.K(D,Z)=DRC.K(D)*(ATTH.K(D,Z)/TTATTH.K(D))*
  TARLML.K(D)                                                   84, A
    RC     - RESID CONST (UNITS)
    DRC    - DESIRED RESID CONST (UNITS)
    ATTH   - ATTRACTIVENESS TO HOUSING (D)
    TTATTH - TOTAL ATTRACTIVENESS FOR HSING
    TARLML - TOTAL AVL RES LAND MULTIP (D)

DRC.K(D)=TTHSU.K(D)*RVCML.K(D)
    DRC    - DESIRED RESID CONST (UNITS)                        85, A
    TTHSU  - TOTAL HOUSING UNITS (UNITS)
    RVCML  - RESID VACANCY MULTIP (D)
```

```
RVCML.K(D)=TABHL(TRVCM(*,D),RVC.K(D),-.2,.3,.05)          86, A
TRVCM(*,1)=.06/.055/.05/.05/.03/.008/.002/1E-15/          86.2, T
  1E-15/1E-15/1E-15
TRVCM(*,2)=.06/.055/.05/.05/.03/.008/.002/1E-15/          86.4, T
  1E-15/1E-15/1E-15
TRVCM(*,3)=.008/.006/.004/.0026/.0012/.0008/1E-15/        86.6, T
  1E-15/1E-15/1E-15/1E-15
    RVCML  - RESID VACANCY MULTIP (D)
    TRVCM  - RESID VAC MULTIP (D)
    RVC    - RESID VACANCY (D)

RVC.K(D)=1-(THSUD.K(D)/TTHSU.K(D))                        87, A
    RVC    - RESID VACANCY (D)
    THSUD  - TOTAL HOUSING DEMANDED (UNITS)
    TTHSU  - TOTAL HOUSING UNITS (UNITS)

THSUD.K(D)=TTRP.K(D)/PPHSU.K(D)                           88, A
    THSUD  - TOTAL HOUSING DEMANDED (UNITS)
    TTRP   - TOTAL POP BY RESID PREF (MEN)
    PPHSU  - MEN PER UNIT (MEN/UNIT)

TTRP.K(D)=SUMV(RPF.K(*,D),2,ACS)                          89, A
    TTRP   - TOTAL POP BY RESID PREF (MEN)
    RPF    - RESID POP FRACTION PREFERRING LOW DENS
               (MEN)
    ACS    - AGE CLASSES

RPF.K(AC2,1)=POP.K(AC2)*HDFRAC(AC2)*(1+CHPP.K(AC2)) 90, A
    RPF    - RESID POP FRACTION PREFERRING LOW DENS
               (MEN)
    POP    - INITIAL POP (MEN)
    HDFRAC - FRACTION POP PREF H DENS (D)
    CHPP   - CHLDRN PER PARENT (MEN)

RPF.K(1,D)=0                                              91, A
    RPF    - RESID POP FRACTION PREFERRING LOW DENS
               (MEN)

RPF.K(AC2,D2)=POP.K(AC2)-POP.K(AC2)*HDFRAC(AC2)*(1+ 92, A
  CHPP.K(AC2))
HDFRAC=0/.45/.50/.35/.35/.50                              92.3, T
    RPF    - RESID POP FRACTION PREFERRING LOW DENS
               (MEN)
    POP    - INITIAL POP (MEN)
    HDFRAC - FRACTION POP PREF H DENS (D)
    CHPP   - CHLDRN PER PARENT (MEN)
```

```
TARLML.K(D)=MIN(1,TAVLNR.K(D)/(DRC.K(D)*PPHSU.K(D)*  93, A
  ARCF(D)))
ARCF=.02/.08/.08
    TARLML - TOTAL AVL RES LAND MULTIP (D)             93.2, T
    TAVLNR - TOTAL AVAIL RESIS LAND BY DENS (ACRE)
    DRC    - DESIRED RESID CONST (UNITS)
    PPHSU  - MEN PER UNIT (MEN/UNIT)
    ARCF   - AVERAGE RESID CONST FACTOR (ACRES/MAN)




  LAND USE ACCOUNTS SECTOR

TL=174908.8/47702.4/47702.4/47702.4/77552/46531.2/  93.8, T
  62041.6/124083.2/26112/117216/44281.6/39072/
  31257.6/29932.8/39680
    TL     - TOTAL ZONAL LAND (ACRES)

ZDL.K(Z)=TL(Z)-MAX((1-DVLNF(Z))*TL(Z),RECLN.K(Z))    95, A
DVLNF=.9/.9/.9/.9/.9/.9/.9/.9/.9/.9/.9/.9/.9/.9/.9  95.2, T
    ZDL    - ZONAL DEVELOPABLE LAND (ACRES)
    TL     - TOTAL ZONAL LAND (ACRES)
    DVLNF  - TABLE, DEVEL LAND FRACT (D)
    RECLN  - RECREATIONAL LAND (ACRES)

RECLN.K(Z)=TABHL(TRECLN(*,Z),TIME.K,1960,1968,8)     96, A
TRECLN(*,1)=3000/12000                               96.2, T
TRECLN(*,2)=4000/10000                               96.3, T
TRECLN(*,3)=10000/13000                              96.4, T
TRECLN(*,4)=3000/5000                                96.5, T
TRECLN(*,5)=2000/3000                                96.6, T
TRECLN(*,6)=4000/4000                                96.7, T
TRECLN(*,7)=2000/3000                                96.8, T
TRECLN(*,8)=2000/5000                                96.9, T
TRECLN(*,9)=2000/2000                                97.1, T
TRECLN(*,10)=700/1000                                97.2, T
TRECLN(*,11)=700/1500                                97.3, T
TRECLN(*,12)=200/9000                                97.4, T
TRECLN(*,13)=700/1500                                97.5, T
TRECLN(*,14)=700/1000                                97.6, T
TRECLN(*,15)=9000/9000                               97.7, T
    RECLN  - RECREATIONAL LAND (ACRES)
    TRECLN - RECREATIONAL LAND (ACRES)
    TIME   - EMPLOYMENT SECTOR RELATIVE WAGES
```

```
ZUL.K(Z)=ZDL.K(Z)/(1+ODEV(Z))                                      98, A
ODEV=.25/.25/.25/.25/.25/.25/.25/.25/.25/.25/.25/                 98.1, T
  .25/.25/.25/.25
    ZUL     - ZONAL USABLE LAND (ACRES)
    ZDL     - ZONAL DEVELOPABLE LAND (ACRES)
    ODEV    - TABLE, OTHER DEVEL FRACTION (D

AVAL.K(Z)=ZUL.K(Z)-INDLND.K(Z)-TRL.K(Z)                            99, A
    AVAL    - ZONAL AVAIL LAND (ACRES)
    ZUL     - ZONAL USABLE LAND (ACRES)
    INDLND  - INITIAL IND LAND (ACRES)
    TRL     - TOTAL ZONAL RESID LAND (ACRES)

TRL.K(Z)=SUMV(RL.K(*,Z),1,DENS)                                   100, A
    TRL     - TOTAL ZONAL RESID LAND (ACRES)
    RL      - RESIDENTIAL LAND (ACRES)

AVLN.K(Z)=MAX(AVAL.K(Z),1E-15)                                    101, A
    AVLN    - ACTUAL AVAIL LAND (ACRES)
    AVAL    - ZONAL AVAIL LAND (ACRES)


CLHSU.KL(2,Z)=-MIN(0,AVAL.K(Z))/(RCF(2,Z)*                        102, R
  PPHSU.K(2))
    CLHSU   - CLEARED LOW DENS NON-SEWERED
    AVAL    - ZONAL AVAIL LAND (ACRES)
    RCF     - RESID CONST FACTORS (ACRES/MAN)
    PPHSU   - MEN PER UNIT (MEN/UNIT)

CLHSU.KL(1,Z)=0                                                   103, R
    CLHSU   - CLEARED LOW DENS NON-SEWERED

CLHSU.KL(3,Z)=0                                                   104, R
    CLHSU   - CLEARED LOW DENS NON-SEWERED

SAT.K(Z)=(TRL.K(Z)+INDLND.K(Z))/ZUL.K(Z)                          105, A
    SAT     - ZONAL DEVEL SATURATION (D)
    TRL     - TOTAL ZONAL RESID LAND (ACRES)
    INDLND  - INITIAL IND LAND (ACRES)
    ZUL     - ZONAL USABLE LAND (ACRES)
```

SEWER SERVICE SECTOR

```
SEWCAP.K(Z)=TABHL(TTCAP(*$Z),TIME.K,1960,1968,8)+     106, A
  STEP(ITCAP(Z),ITCI(Z))
TTCAP(*,1)=2919000/5728000                            106.3, T
TTCAP(*,2)=9447000/14796000                           106.4, T
TTCAP(*,3)=30384000/47309000                          106.5, T
TTCAP(*,4)=7856000/22717000                           106.6, T
TTCAP(*,5)=6584000/12923000                           106.7, T
TTCAP(*,6)=31762000/37113000                          106.8, T
TTCAP(*,7)=18013000/28480000                          106.9, T
TTCAP(*,8)=141000/1565000                             107.1, T
TTCAP(*,9)=20786000/23743000                          107.2, T
TTCAP(*,10)=10744000/16958000                         107.3, T
TTCAP(*,11)=2140000/4717000                           107.4, T
TTCAP(*,12)=315000/4897000                            107.5, T
TTCAP(*,13)=9298000/15246000                          107.6, T
TTCAP(*,14)=3633000/4685000                           107.7, T
TTCAP(*,15)=59280000/62521000                         107.8, T
ITCAP=630000/1500000/5000000/2500000/2000000/         108.1, T
  4400000/3400000/220000/3400000/1900000/520000/
  540000/1600000/510000/0
ITCI=1976/1976/1976/1976/1976/1976/1976/1976/1976/    108.4, T
  1976/1976/1976/1976/1976/1976
    SEWCAP - SEWER TREATMENT CAPACITY (GAL)
    TTCAP  - TREATMENT CAPACITY (GALS)
    TIME   - EMPLOYMENT SECTOR RELATIVE WAGES
    ITCAP  - INVESTMENTS IN TRTMT CAP (GALS)
    ITCI   - TIME OF TRTMT CAP INVSTMT (YR)


SWUSE.K(Z)=ZEPWK.K(Z)*INSWF+ZRP.K(1,Z)*RSWF(1)+       109, A
  ZRP.K(2,Z)*RSWF(2)
RSWF=40/70                                            109.2, T
INSWF=30                                              109.3, C
    SWUSE  - SEWER USE (GAL)
    ZEPWK  - ZONAL EMPLOYMENT (MEN)
    INSWF  - IND SEWER USE FACTOR (GALS)
    ZRP    - ZONAL RESID POP (MEN)
    RSWF   - RESID SEWER USE FACTOR (GALS)

ZRP.K(D,Z)=HSU.K(D,Z)*PPHSU.K(D)                      110, A
    ZRP    - ZONAL RESID POP (MEN)
    HSU    - INITIAL HOUSING UNITS (UNITS)
    PPHSU  - MEN PER UNIT (MEN/UNIT)

EXCAP.K(Z)=MAX(1,SEWCAP.K(Z)-SWUSE.K(Z))              111, A
    EXCAP  - EXCESS CAPACITY (GAL)
    SEWCAP - SEWER TREATMENT CAPACITY (GAL)
    SWUSE  - SEWER USE (GAL)
```

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IAVLNI.K(Z)=MAX(1E-15,(EXCAP.K(Z)/INSWF)*INCNF.K(Z) 112, A
  *LPOL.K(Z))
     IAVLNI - INDICTD AVAIL IND LAND (ACRES)
     EXCAP  - EXCESS CAPACITY (GAL)
     INSWF  - IND SEWFR USE FACTOR (GALS)
     INCNF  - INITIAL INU DENS .(ACRES/MAN)
     LPOL   - LOCAL SFWER HOOK-UP POLICY (D)

LPOL.K(Z)=TABHL(LPOLT(*,Z),TIME.K,1960,1980,2)           113, A
LPOLT(*,1)=1/1/1/1/1/1/0/0/0/1/1                         113.2, T
LPOLT(*,2)=1/1/1/1/1/.5/0/0/0/1/1                        113.3, T
LPOLT(*,3)=1/1/1/1/1/.5/0/0/0/1/1                        113.4, T
LPOLT(*,4)=1/1/1/1/1/1/0/0/0/1/1                         113.5, T
LPOLT(*,5)=1/1/1/1/1/0/0/0/0/1/1                         113.6, T
LPOLT(*,6)=1/1/1/1/1/0/0/0/0/1/1                         113.7, T
LPOLT(*,7)=1/1/1/1/1/0/0/0/0/1/1                         113.8, T
LPOLT(*,8)=1/1/1/1/1/0/0/0/0/1/1                         113.9, T
LPOLT(*,9)=1/1/1/1/1/1/1/1/1/1/1                         114.1, T
LPOLT(*,10)=1/1/1/1/1/1/0/0/0/1/1                        114.2, T
LPOLT(*,11)=1/1/1/1/1/1/0/0/0/1/1                        114.3, T
LPOLT(*,12)=1/1/1/1/1/1/0/0/0/1/1                        114.4, T
LPOLT(*,13)=1/1/1/1/1/1/0/0/0/1/1                        114.5, T
LPOLT(*,14)=1/1/1/1/1/1/0/0/0/1/1                        114.6, T
LPOLT(*,15)=1/1/1/1/1/1/1/1/1/1/1                        114.7, T
     LPOL   - LOCAL SEWER HOOK-UP POLICY (D)
     LPOLT  - TABLE, LOCAL SEWER SERVICE POLICY (D)
     TIME   - EMPLOYMENT SECTOR RELATIVE WAGES

DIALNI.K(Z)=DELAY1(IAVLNI.K(Z)/3,DSD)                    115, A
DSD=1                                                    115.3, C
     DIALNI - DELAYED INDICATED AVAIL IND LAND (ACRES)
     IAVLNI - INDICTD AVAIL IND LAND (ACRES)
     DSD    - DELAY BETW PERMIT AND CONST (YR)


SALI.K(Z)=MAX(IAVLNI.K(Z),DIALNI.K(Z))                   116, A
     SALI   - SANCTIONED AVAIL LAND (ACRES)
     IAVLNI - INDICTD AVAIL IND LAND (ACRES)
     DIALNI - DELAYED INDICATED AVAIL IND LAND (ACRES)

AVLNI.K(Z)=SEWSW*SALI.K(Z)+(1-SEWSW)*MIN(SALI.K(Z),  117, A
  ASVAR.K(Z))
SEWSW=0                                              117.2, C
     AVLNI  - ACTUAL AVAIL IND LAND (ACRES)
     SEWSW  - SEWER SWITCH (D)
     SALI   - SANCTIONED AVAIL LAND (ACRES)
     ASVAR  - AVAIL SERVICE AREA (ACRES)
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ASVAR.K(Z)=MAX(1,(SVAREA.K(Z)-(INDLND.K(Z)+RL.K(1,   118, A
  Z)+RL.K(2,Z))(1+ODEV(Z)))) 
    ASVAR  - AVAIL SERVICE AREA (ACRES)
    SVAREA - TOTAL SERVICEAREA (ACRES)
    INDLND - INITIAL IND LAND (ACRES)
    RL     - RESIDENTIAL LAND (ACRES)
    ODEV   - TABLE, OTHER DEVEL FRACTION (D

SVAREA.K(Z)=TABHL(TSAR(*,Z),TIME.K,1960,1976,16)+    119, A
  STEP(ISA(Z),ISAT(Z))
TSAR(*,1)=3406/22941
TSAR(*,2)=8851/23713                                 119.2, T
TSAR(*,3)=24096/43866                                119.3, T
TSAR(*,4)=546/12349                                  119.4, T
TSAR(*,5)=6088/18610                                 119.5, T
TSAR(*,6)=21204/35633                                119.6, T
TSAR(*,7)=19486/43480                                119.7, T
TSAR(*,8)=0/18396                                    119.8, T
TSAR(*,9)=15550/24870                                119.9, T
TSAR(*,10)=17815/30831                               120.1, T
TSAR(*,11)=4835/27872                                120.2, T
TSAR(*,12)=1735/55701                                120.3, T
TSAR(*,13)=10666/23927                               120.4, T
TSAR(*,14)=2763/5832                                 120.5, T
TSAR(*,15)=23566/37649                               120.6, T
                                                     120.7, T
ISA=200/4000/6000/1000/2000/5000/4000/1000/4000/,    120.9, T
  2000/2000/1000/2000/1000/0
ISAT=1976/1976/1976/1976/1976/1976/1976/1976/1976/   121.3, T
  1976/1976/1976/1976/1976/1976
    SVAREA - TOTAL SERVICEAREA (ACRES)
    TSAR   - TABLE, SERVICE AREA
    TIME   - EMPLOYMENT SECTOR RELATIVE WAGES
    ISA    - TABLE,SERVICE AREA INVSTMTS (ACRES)

IAVLNR.K(DS,Z)=MAX(1E-15,(EXCAP.K(Z)/(RSWF(DS)*      122, A
  RCF.K(DS,Z)*LPOL.K(Z))))
    IAVLNR - INDICATED AVAIL RESID LAND (ACRES)
    EXCAP  - EXCESS CAPACITY (GAL)
    RSWF   - RESID SEWER USE FACTOR (GALS)
    RCF    - RESID CONST FACTORS (ACRES/MAN)
    LPOL   - LOCAL SEWER HOOK-UP POLICY (D)


DIALNR.K(DS,Z)=DELAY1(IAVLNR.K(DS,Z)/3,DSD)          123, A
    DIALNR - DELAYED INDICATED AVAIL RESID LAND (ACRES)
    IAVLNR - INDICATED AVAIL RESID LAND (ACRES)
    DSD    - DELAY BETW PERMIT AND CONST (YR)
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SALR.K(DS,Z)=MAX(IAVLNR.K(DS,Z),DIALNR.K(DS,Z))          124, A
     SALR   - SANCTIONED AVAIL RESID LAND (ACRES)
     IAVLNR - INDICATED AVAIL RESID LAND (ACRES)
     DIALNR - DELAYED INDICATED AVAIL RESID LAND (ACRES)

AVLNR.K(DS,Z)=SEWSW*SALR.K(DS,Z)+(1-SEWSW)*               125, A
  MIN(SALR.K(DS,Z),ASVAR.K(Z))
     AVLNR  - ZONAL ATTRACTIVENESS FOR INDUSTRIAL
                 DEVELOPMENT
     SEWSW  - SEWER SWITCH (D)
     SALR   - SANCTIONED AVAIL RESID LAND (ACRES)
     ASVAR  - AVAIL SERVICE AREA (ACRES)

AVLNR.K(3,Z)=ZDL.K(Z)-SVAREA.K(Z)-RL.K(3,Z)               126, A
     AVLNR  - ZONAL ATTRACTIVENESS FOR INDUSTRIAL
                 DEVELOPMENT
     ZDL    - ZONAL DEVELOPABLE LAND (ACRES)
     SVAREA - TOTAL SERVICEAREA (ACRES)
     RL     - RESIDENTIAL LAND (ACRES)


ATIND.K(Z)=(WS*SATML.K(Z)+WAC*ACLAB.K(Z))(WL*             127, A
  FAVLNI.K(Z))
     ATIND  - ATTRACTIVENESS FOR INDUSTRY (D)
     WS     - WEIGHT GIVEN TO SATURATION IN
                 ATTRACTIVENESS FCT (D)
     SATML  - SATURATION MULTIP (D)
     WAC    - WEIGHT GIVEN TO LABOR ACCESSI-BILITY FACTOR
                (D)
     ACLAB  - ACCESS TO LABOR (D)
     WL     - WEIGHT GIVEN TO AVAIL LAND FACTOR (D)
     FAVLNI - FRACTION AVAILABLE IND LAND IN EACH ZONE
                (D)

TTATIN.K=SUMV(ATIND.K,1,ZNS)                               128, A
     TTATIN - TOTAL ATTRACTIVENESS FOR IND (D)
     ATIND  - ATTRACTIVENESS FOR INDUSTRY (D)

SATML.K(Z)=TABHL(TSTML,SAT.K,.5,1.0,.05)                   129, A
TSTML=1/1/1/1/1/1/.95/.9/.85/.8/.75                        129.2, T
WS=1                                                       129.4, C
     SATML  - SATURATION MULTIP (D)
     TSTML  - TABLE,SAT MULTIP FOR IND (D)
     SAT    - ZONAL DEVEL SATURATION (D)
     WS     - WEIGHT GIVEN TO SATURATION IN
                 ATTRACTIVENESS FCT (D)

ACLAB.K(Z)=SUMVV(LBF.K,1,ZNS,IAF.K(*,Z),1,ZNS)             130, A
     ACLAB  - ACCESS TO LABOR (D)
     LBF    - LABOR FORCE
     IAF    - INDUSTRIAL ACCESS FACTOR (D)
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LBF.K(Z)=DELAY1(LAB.K(Z),LBFDEL)
LBFDEL=1                                                  131, A
    LBF    - LABOR FORCE                                  131.2, C
    LAB    - LABOR POTENTIAL (MEN)
    LBFDEL - LABOR FORCE DELAY (YRS)

LAB.K(Z)=SUMV(ZRP.K(*,Z),1,DENS)*AGLFPR.K
WAC=1                                                     132, A
    LAB    - LABOR POTENTIAL (MEN)                        132.2, C
    ZRP    - ZONAL RESID POP (MEN)
    AGLFPR - AGGREGATE LABOR FORCE PARTICIPATION (D)
                TOTAL LABOR FORCE FORECAST
    WAC    - WEIGHT GIVEN TO LABOR ACCESSI-BILITY FACTOR
                (D)

FAVLNI.K(Z)=AVLNI.K(Z)/TAVLNI.K
    FAVLNI - FRACTION AVAILABLE IND LAND IN EACH ZONE      133, A
                (D)
    AVLNI  - ACTUAL AVAIL IND LAND (ACRES)
    TAVLNI - TOTAL AVAILABLE IND LAND (ACRES)

TAVLNI.K=SUMV(AVLNI.K,1,ZNS)
WL=1                                                      134, A
    TAVLNI - TOTAL AVAILABLE IND LAND (ACRES)             134.1, C
    AVLNI  - ACTUAL AVAIL IND LAND (ACRES)
    WL     - WEIGHT GIVEN TO AVAIL LAND FACTOR (D)

IAF.K(ZT,ZF)=TABHL(ISLT,TT.K(ZT,ZF),0,60,10)
ISLT=1.0/1.0/.8/.7/.5/.4/.2                               135, A
    IAF    - INDUSTRIAL ACCESS FACTOR (D)                 135.2, C
    ISLT   - TABLE, IND ACCESS FACTOR (D)

    ATTRACTIVENESS FOR RESIDENTIAL DEVELOPMENT

ATTH.K(D,Z)=(WS*DSATML.K(D,Z)+WAC*RACEMP.K(D,Z))*
  (WL*FAVLNR.K(D,Z))                                      136, A
    ATTH   - ATTRACTIVENESS TO HOUSING (D)
    WS     - WEIGHT GIVEN TO SATURATION IN
                ATTRACTIVENESS FCT (D)
    DSATML - SATURATION MULTIPLIER BY DENSITY (D)
    WAC    - WEIGHT GIVEN TO LABOR ACCESSI-BILITY FACTOR
                (D)
    RACEMP - RESID ACCESS FACTOR BY DENSITY (D)
    WL     - WEIGHT GIVEN TO AVAIL LAND FACTOR (D)
    FAVLNR - FRACTION OF AVAIL RESID LAND IN EACH ZONE
                (D)

TTATTH.K(D)=SUMV(ATTH.K(D,*),1,ZNS)
    TTATTH - TOTAL ATTRACTIVENESS FOR HSING                137, A
    ATTH   - ATTRACTIVENESS TO HOUSING (D)
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DSATML.K(D,Z)=TABHL(TDML(*,D),SAT.K,.5,1.0,.05)          138, A
TDML(*,1)=1/1/1/1/1/1/1/.7/.2/1E-15                      138.2, T
TDML(*,2)=1/.95/.85/.70/.55/.35/.15/.05/1E-15/           138.4, T
  1E-15/1E-15
TDML(*,3)=1/.95/.85/.70/.55/.35/.15/.05/1E-15/           138.5, T
  1E-15/1E-15
    DSATML - SATURATION MULTIPLIER BY DENSITY (D)
    TDML   - TABLE,RESID DENSITY MULTIP (D)
    SAT    - ZONAL DEVEL SATURATION (D)

RACEMP.K(D,Z)=SUMVV(DIND.K,1,ZNS,RAF.K(*,Z,D),1,        139, A
  ZNS)
    RACEMP - RESID ACCESS FACTOR BY DENSITY (D)
    DIND   - DELAYED INDUSTRY (MEN)
    RAF    - RESID ACCESS FACTORS BY DENS (D)

DIND.K(Z)=DELAY1(ZEPWK.K(Z),INPDEL)                      140, A
INPDEL=1                                                 140.2, C
    DIND   - DELAYED INDUSTRY (MEN)
    ZEPWK  - ZONAL EMPLOYMENT (MEN)
    INPDEL - INDUSTRIAL PERCEPTION DELAY (YR)

RAF.K(ZT,ZF,D)=TABHL(TRA(*,D),TT.K(ZT,ZF),0,60,10)       141, A
TRA(*,1)=1/.9/.7/.5/.3/.1/0.0001                         141.2, T
TRA(*,2)=1/1/.9/.9/.8/.7/.6                              141.3, T
TRA(*,3)=1/1/.9/.9/.8/.7/.6                              141.4, T
    RAF    - RESID ACCESS FACTORS BY DENS (D)
    TRA    - TABLE, WILLINGNESS TO TRAVEL (D)

FAVLNR.K(D,Z)=AVLNR.K(D,Z)/TAVLNR.K(D)                   142, A
    FAVLNR - FRACTION OF AVAIL RESID LAND IN EACH ZONE
               (D)
    AVLNR  - ZONAL ATTRACTIVENESS FOR INDUSTRIAL
               DEVELOPMENT
    TAVLNR - TOTAL AVAIL RESIS LAND BY DENS (ACRE)

TAVLNR.K(D)=SUMV(AVLRTR.K(*,D),1,ZNS)                    143, A
    TAVLNR - TOTAL AVAIL RESIS LAND BY DENS (ACRE)
    AVLRTR - TRANSPOSE OF AVLNR (D)

AVLRTR.K(Z,D)=AVLNR.K(D,Z)                               144, A
    AVLRTR - TRANSPOSE OF AVLNR (D)
    AVLNR  - ZONAL ATTRACTIVENESS FOR INDUSTRIAL
               DEVELOPMENT

    TRAVEL TIMES SECTOR

TT.K(ZT,ZF)=TABHL(TTT(*,ZT,ZF),TIME.K,1960,1969,1)       145, A
    TIME   - EMPLOYMENT SECTOR RELATIVE WAGES
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